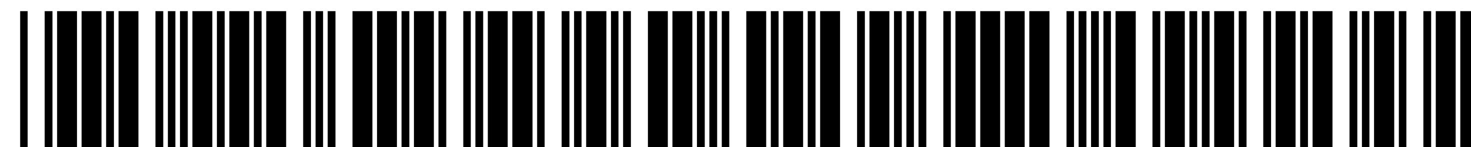

(12) **United States Patent**
Kikai et al.

(10) **Patent No.: US 11,049,739 B2**
(45) **Date of Patent: Jun. 29, 2021**

(54) **ASHING APPARATUS, ASHING METHOD AND RECORDING MEDIUM**

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(72) Inventors: **Takaya Kikai**, Koshi (JP); **Yuzo Ohishi**, Koshi (JP)

(73) Assignee: **TOKYO ELECTRON LIMITED**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 173 days.

(21) Appl. No.: **16/260,342**

(22) Filed: **Jan. 29, 2019**

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(30) **Foreign Application Priority Data**

Jan. 29, 2018 (JP) JP2018-012256

(51) **Int. Cl.**

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H01L 21/3105	(2006.01)
H01L 21/311	(2006.01)
H01L 21/687	(2006.01)

(52) **U.S. Cl.**

CPC .. ***H01L 21/67115*** (2013.01); ***H01L 21/31058*** (2013.01); ***H01L 21/31138*** (2013.01); ***H01L 21/67248*** (2013.01); ***H01L 21/68742*** (2013.01)

(58) **Field of Classification Search**

CPC combination set(s) only.
See application file for complete search history.

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Primary Examiner — Mounir S Amer
(74) *Attorney, Agent, or Firm* — Pearne & Gordon LLP

(57) **ABSTRACT**

An ashing apparatus includes a light irradiating unit configured to irradiate, to a substrate having an organic film formed on a surface thereof, processing light for ashing the organic film; a posture changing unit configured to change a posture of the substrate with respect to the light irradiating unit; and a control unit. The control unit performs: a first processing of controlling the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate while changing the posture of the substrate from a first posture to a second posture; and a second processing of controlling, after the first processing, the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate while changing the posture of the substrate from a third posture different from the first posture to a fourth posture.

9 Claims, 26 Drawing Sheets

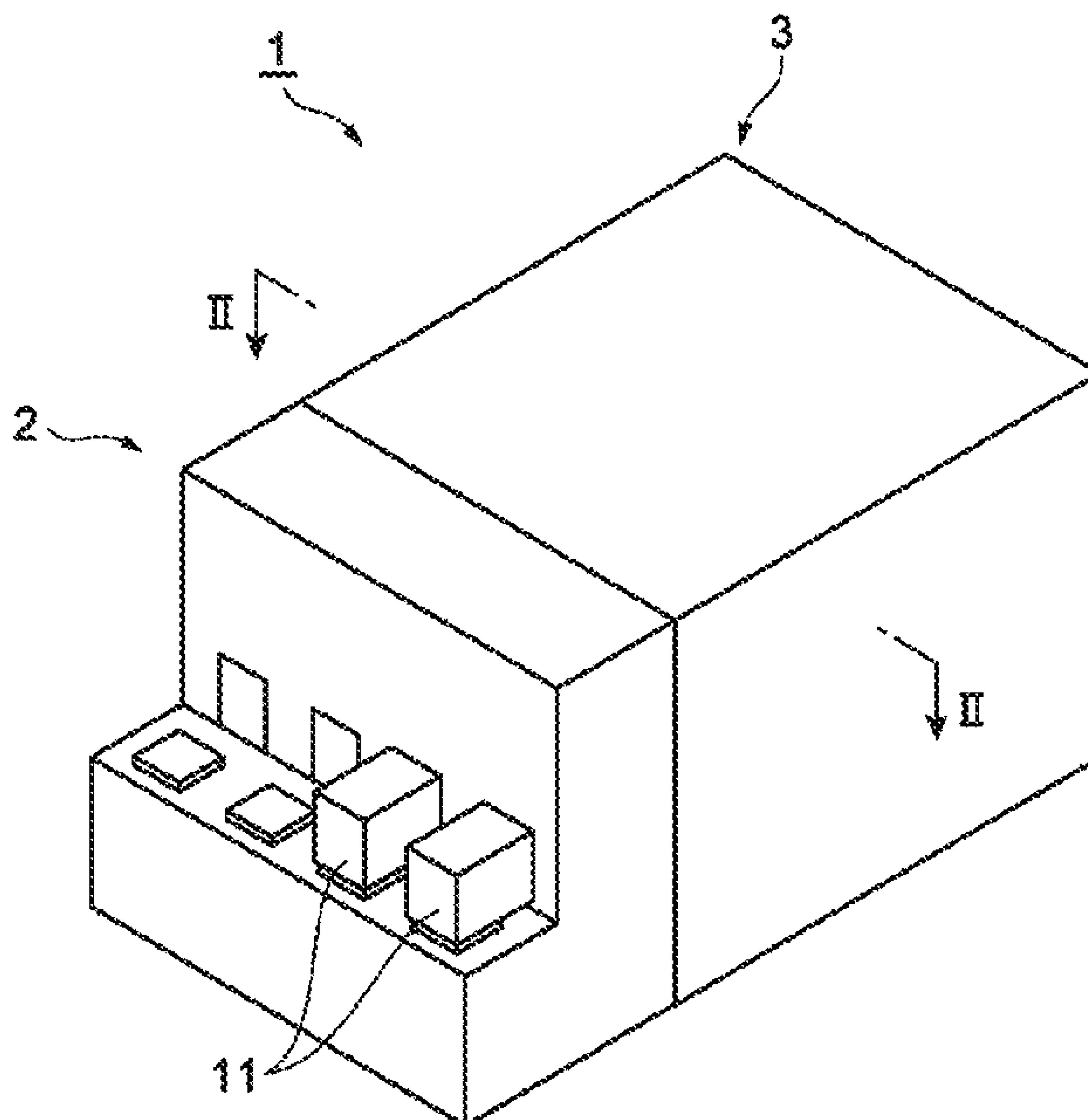


FIG. 1

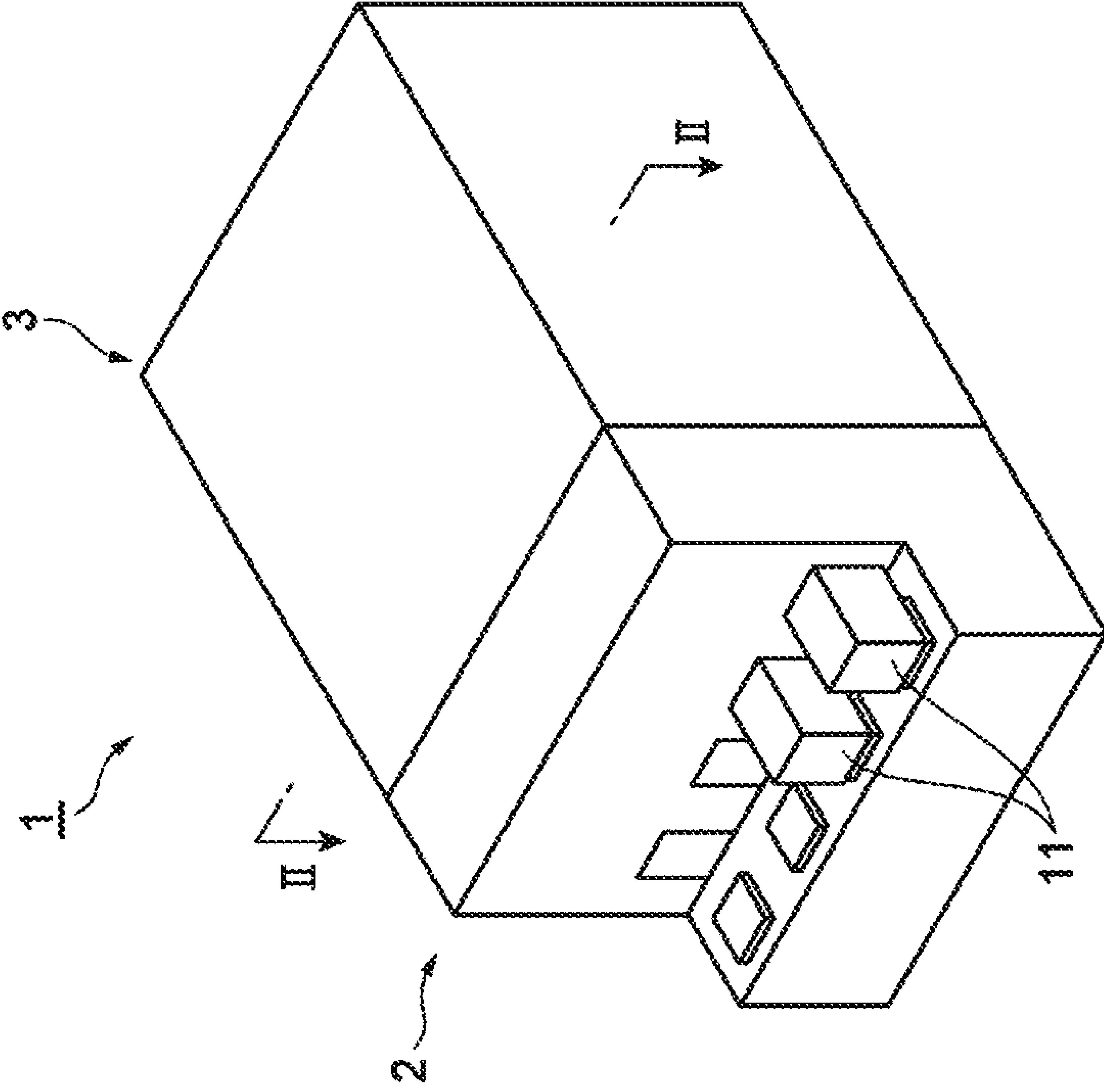


FIG. 2

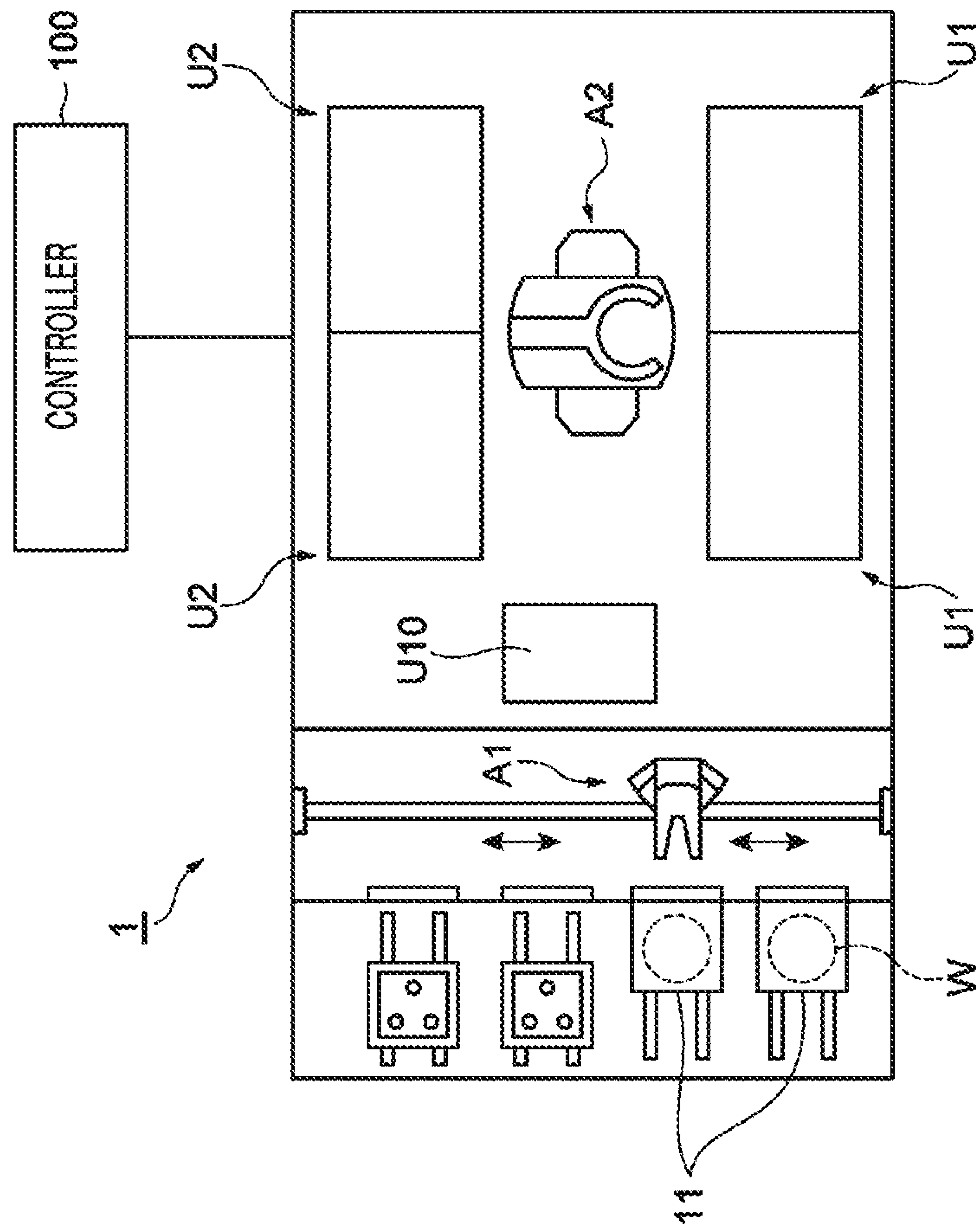


FIG. 3

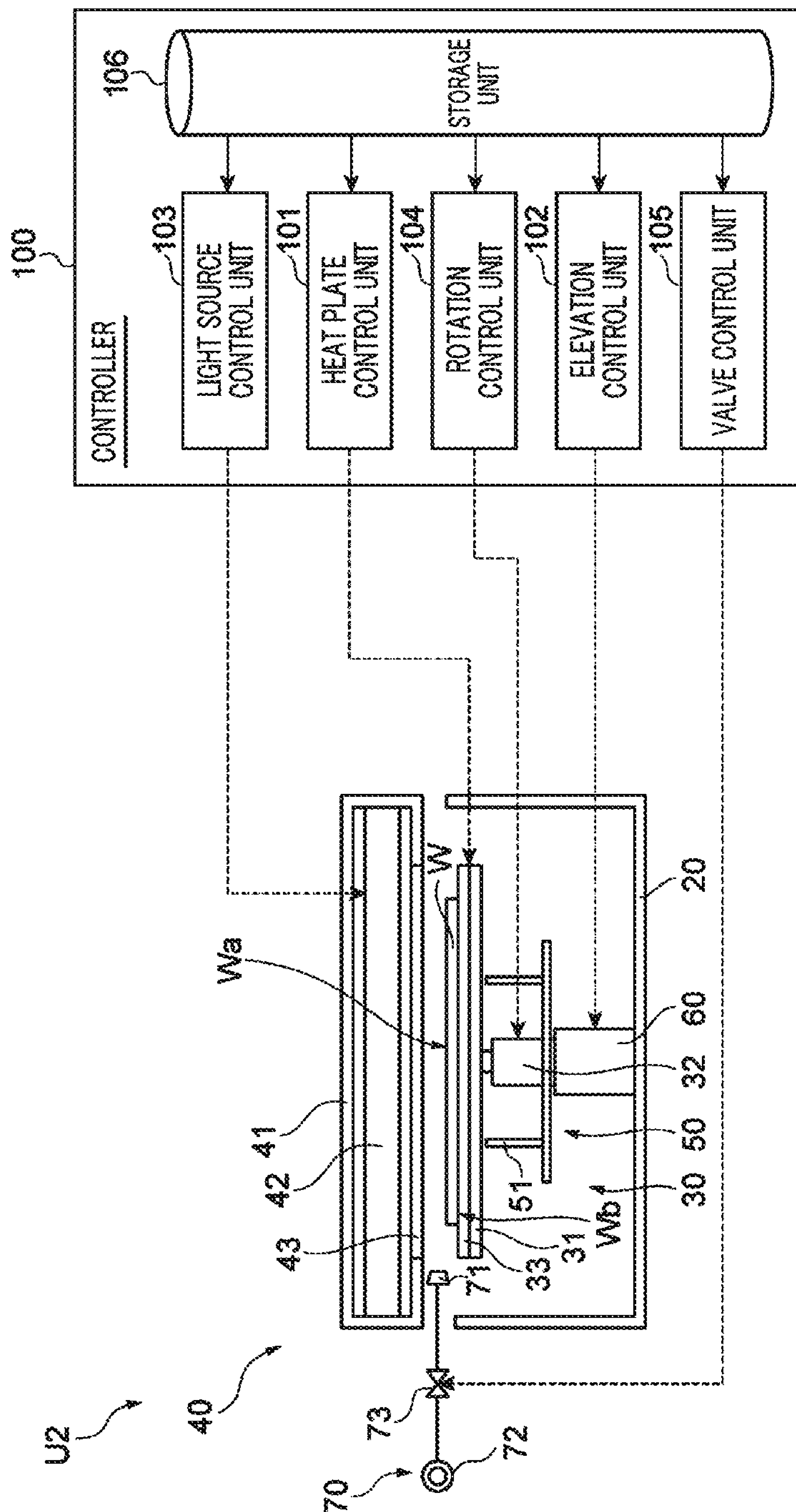


FIG. 4

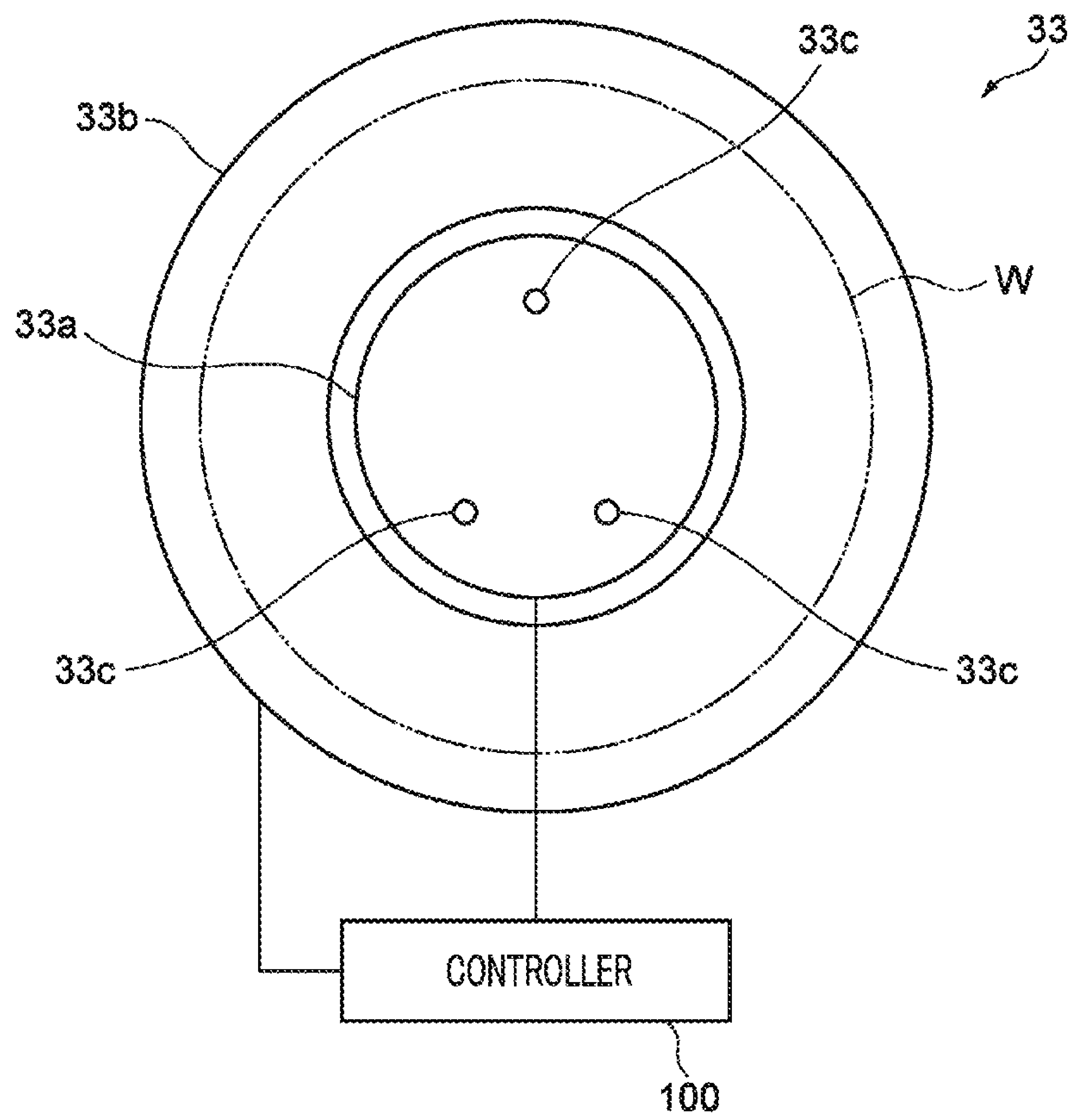


FIG. 5

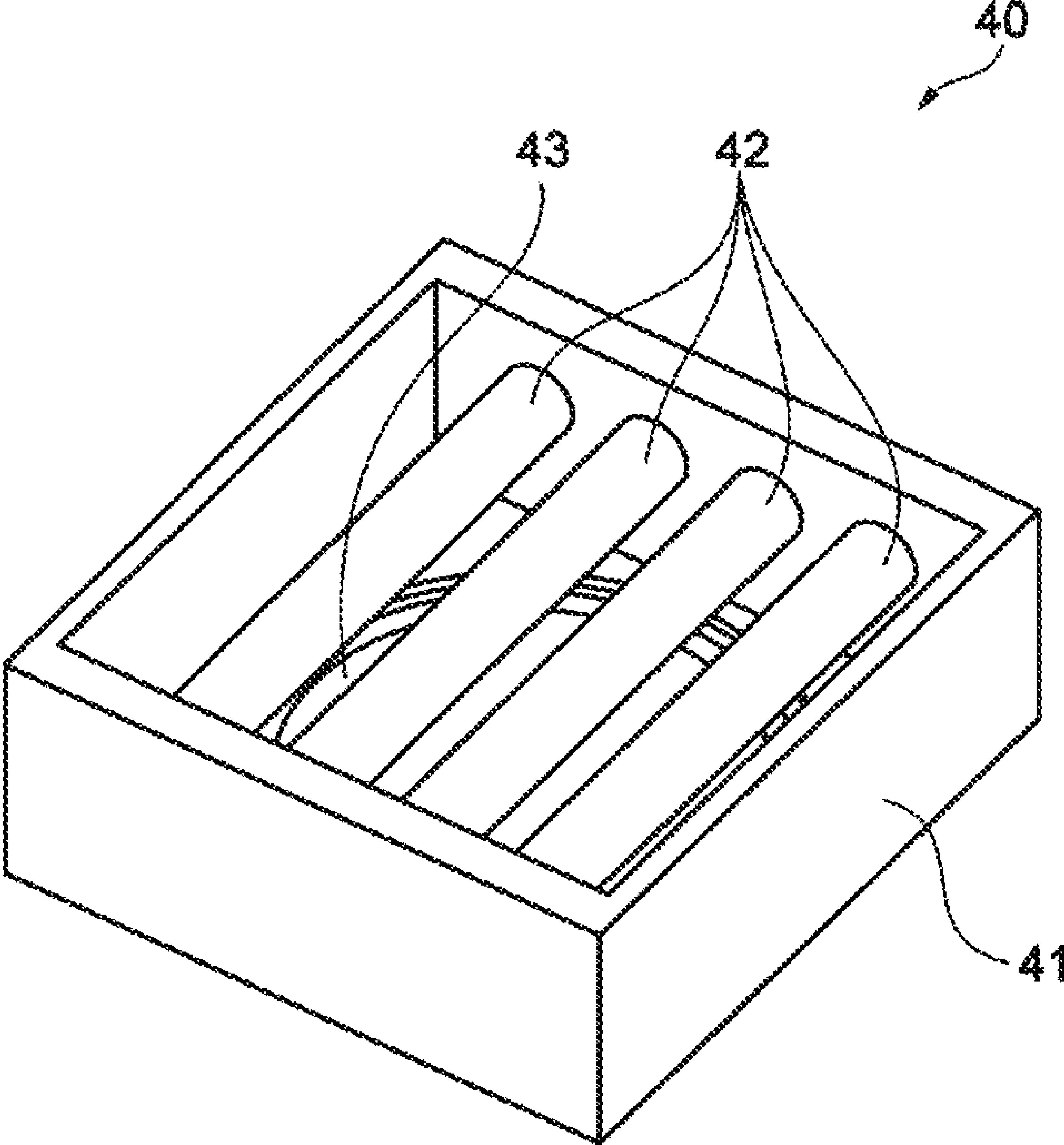


FIG. 6

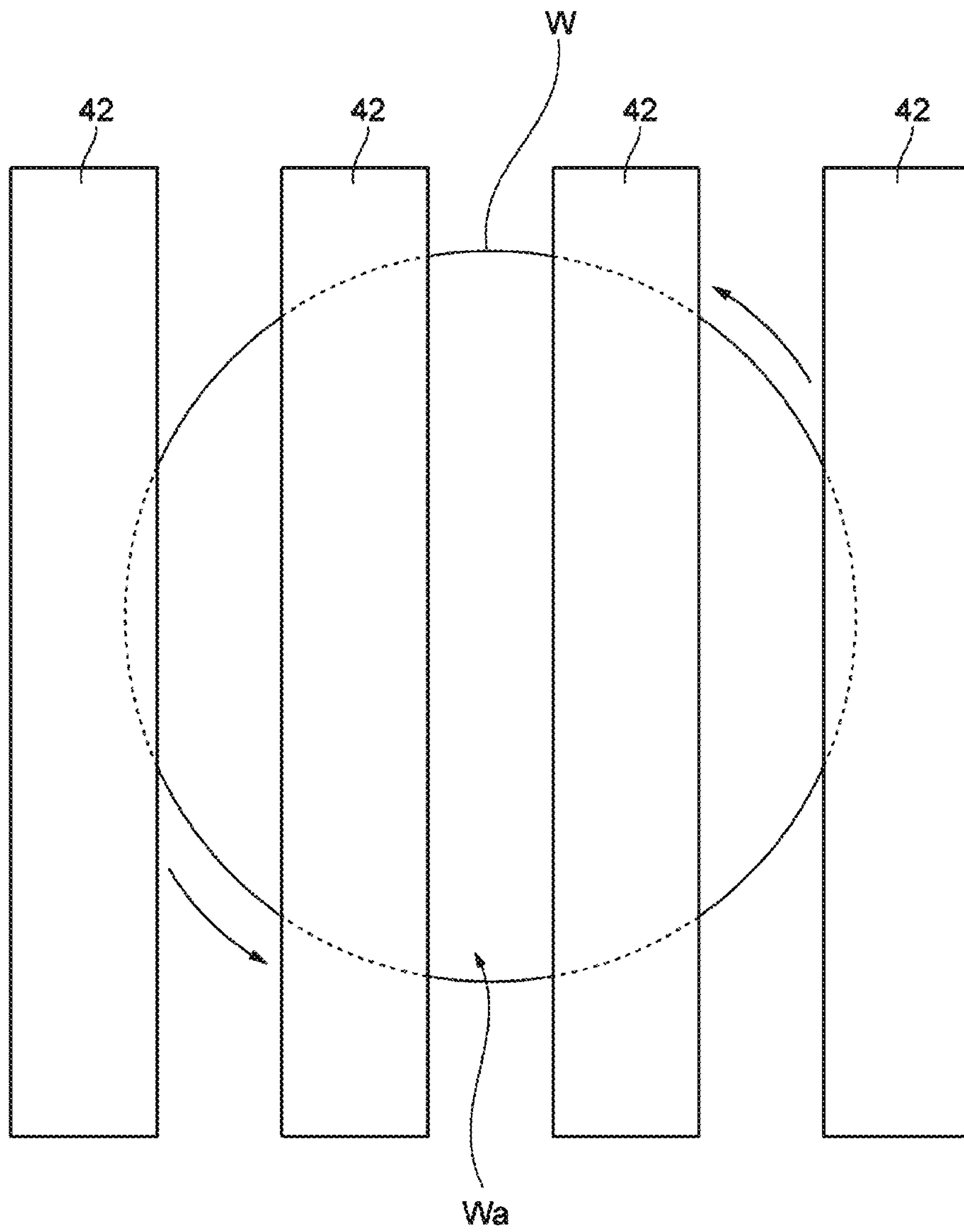


FIG. 7

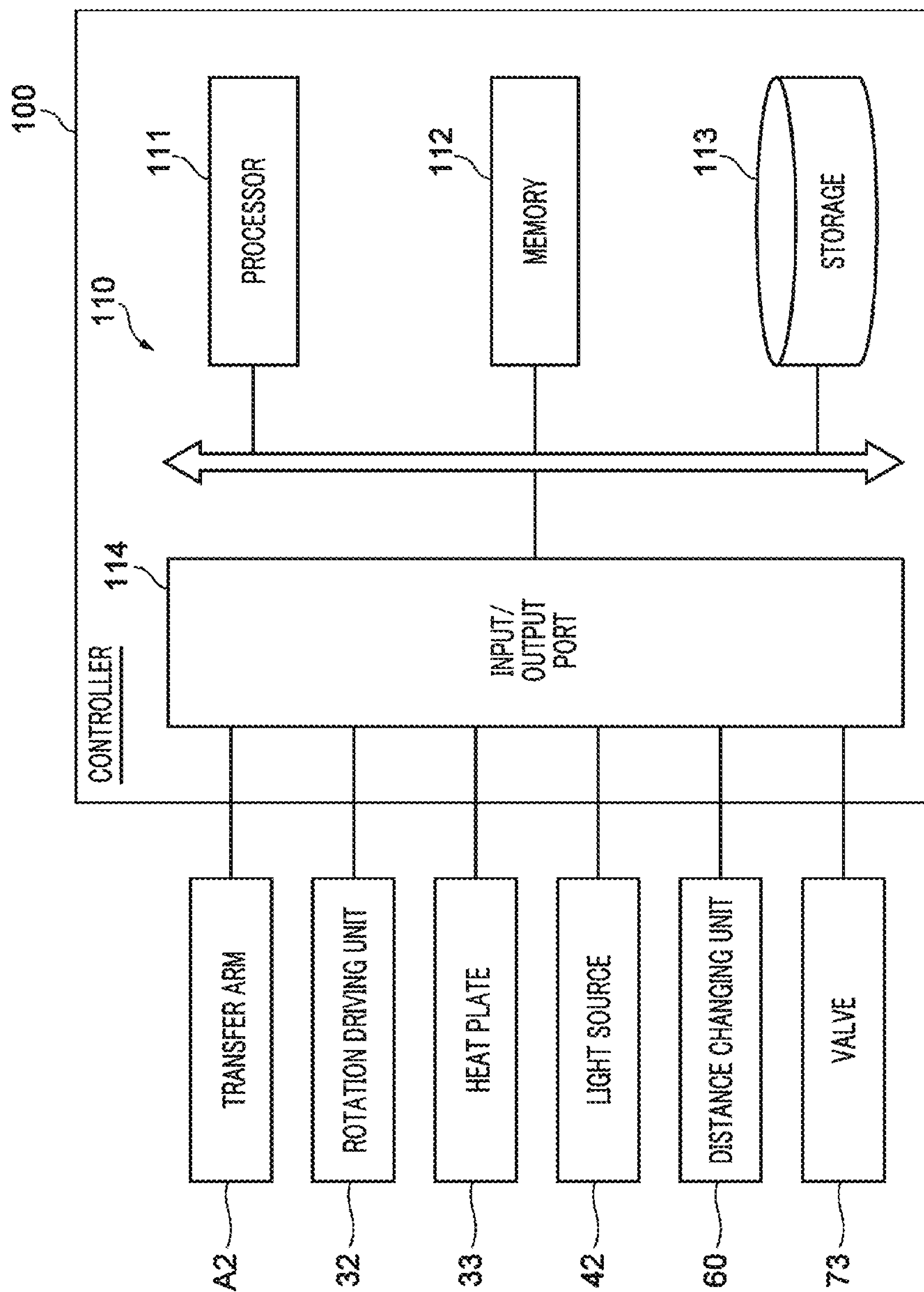


FIG. 8

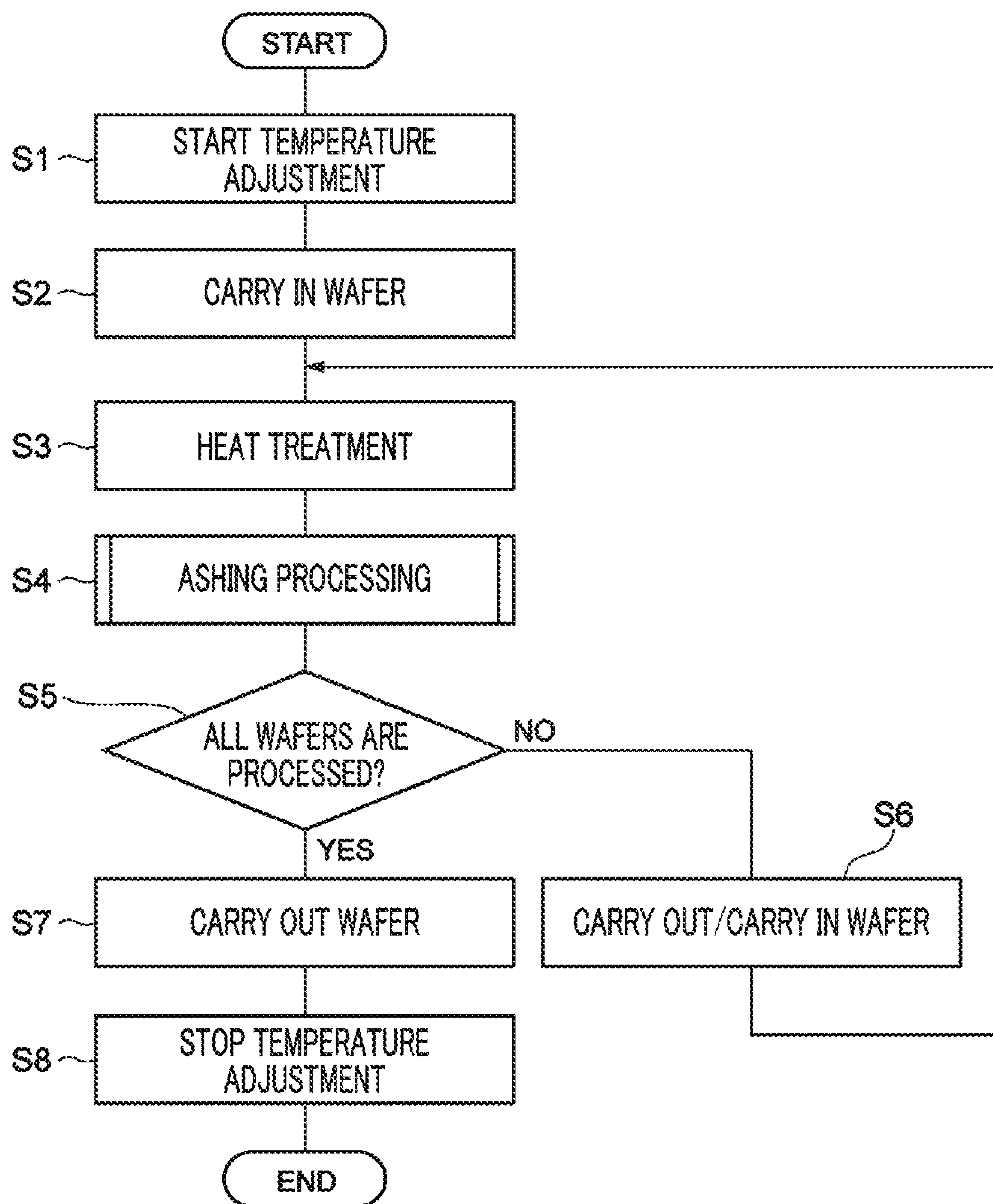


FIG. 9

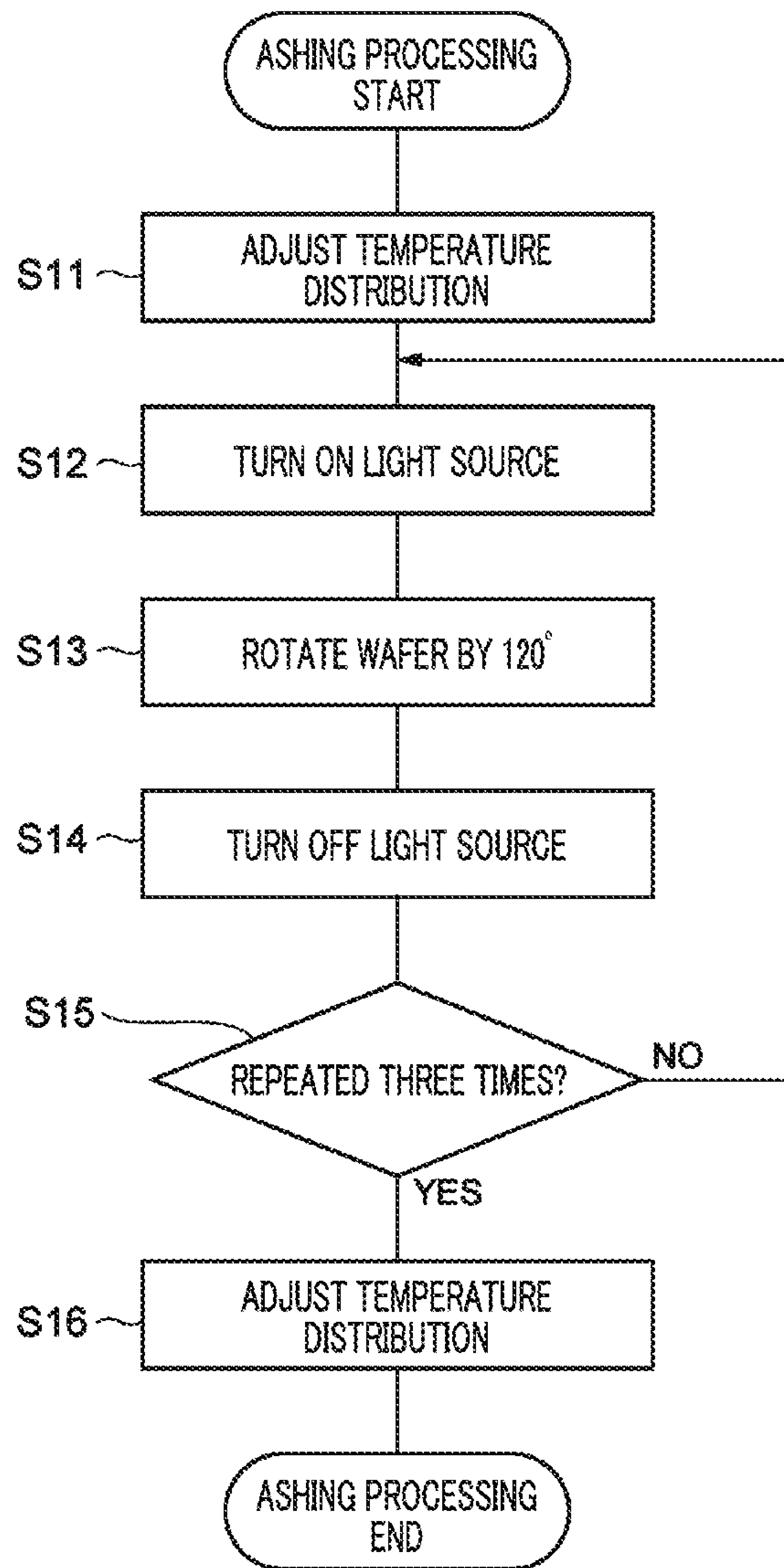


FIG. 10A

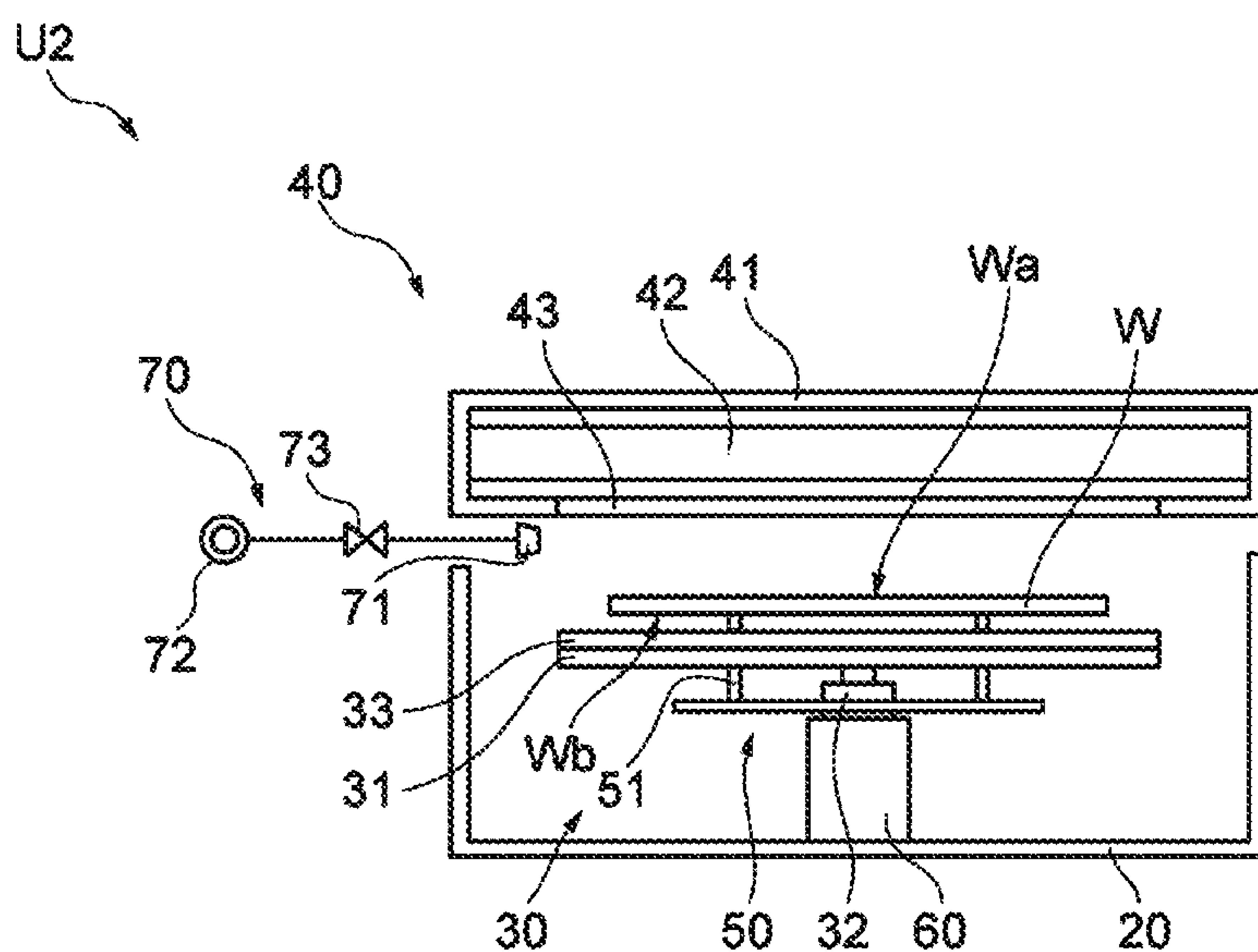


FIG. 10B

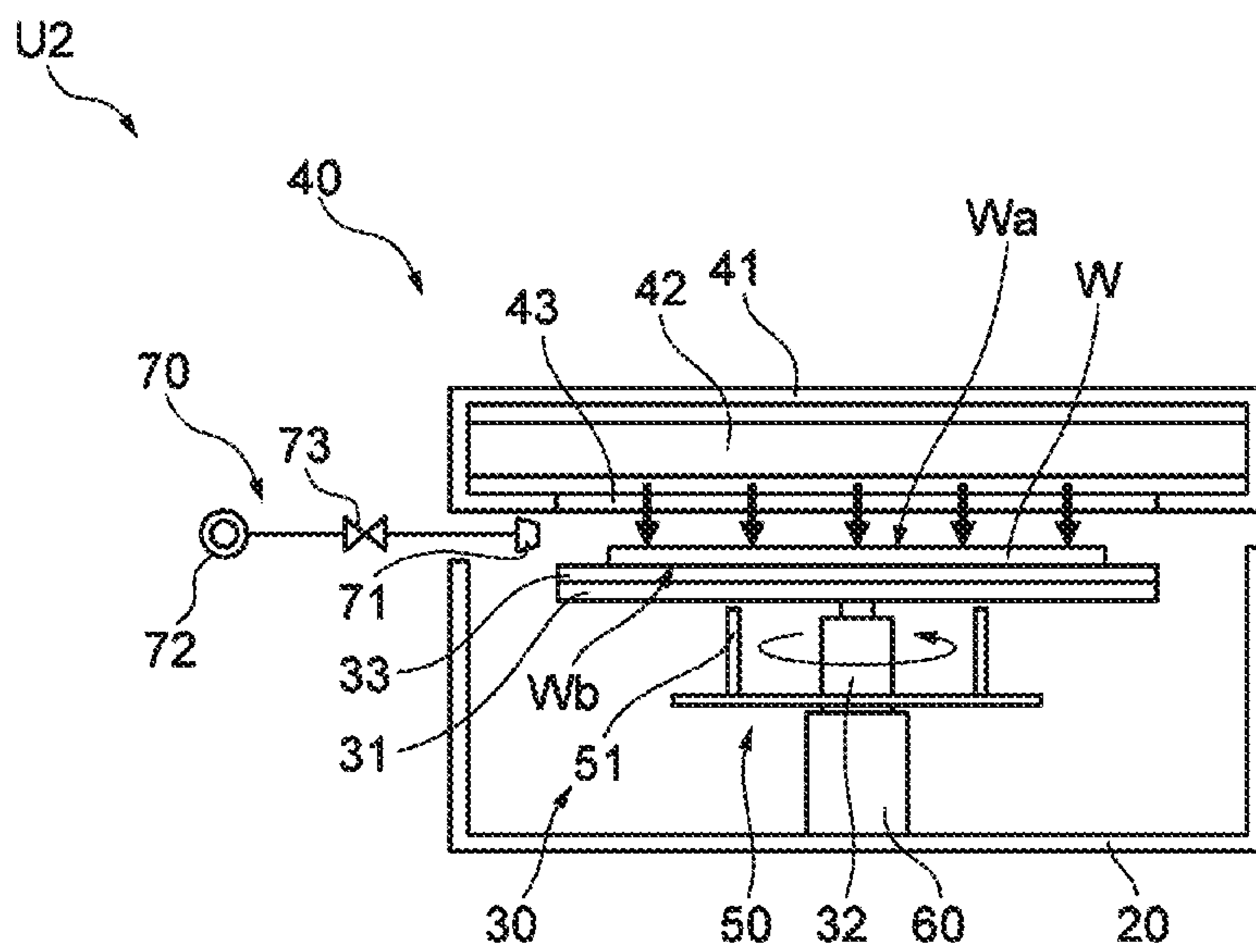


FIG. 11A

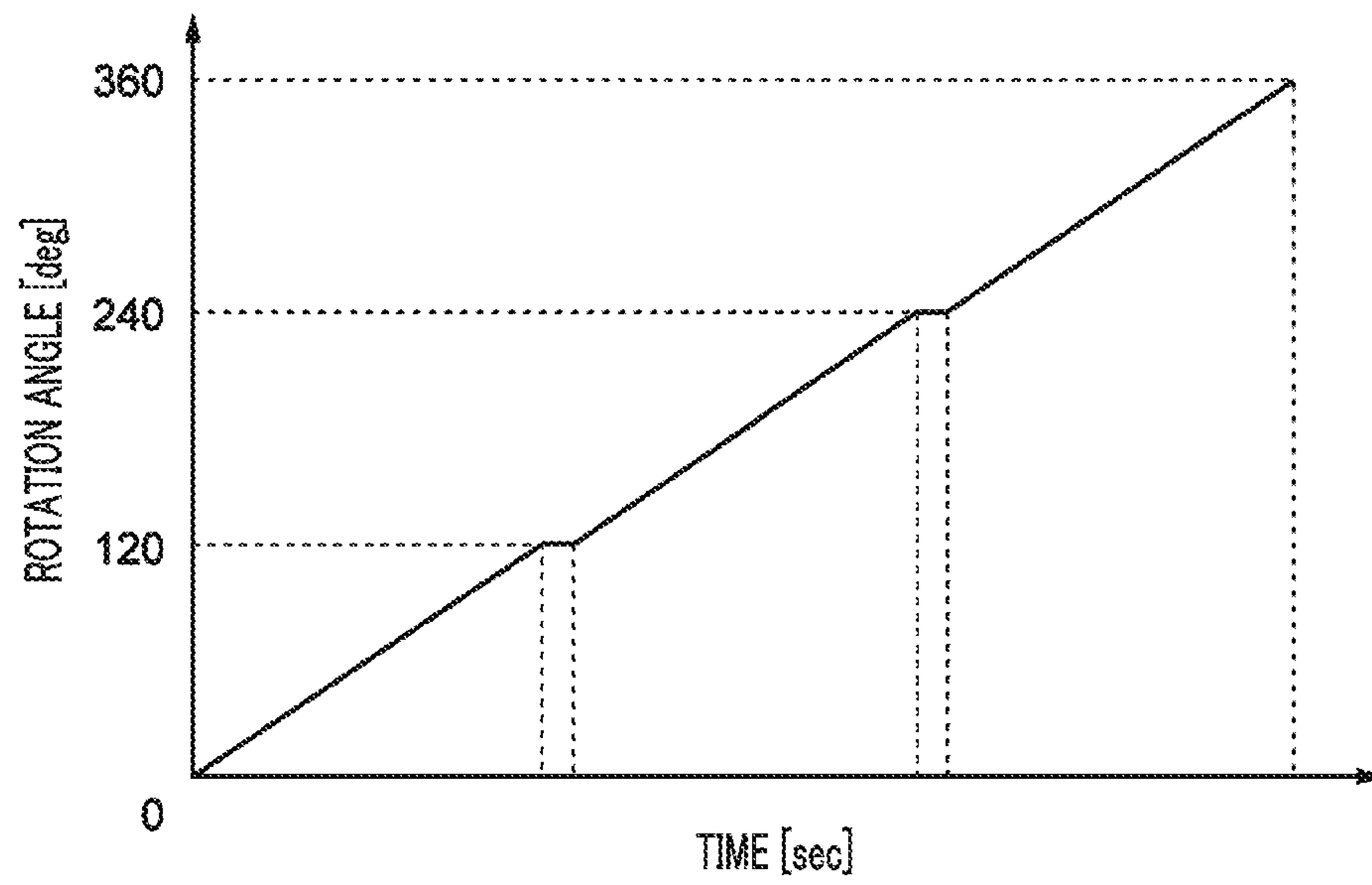


FIG. 11B

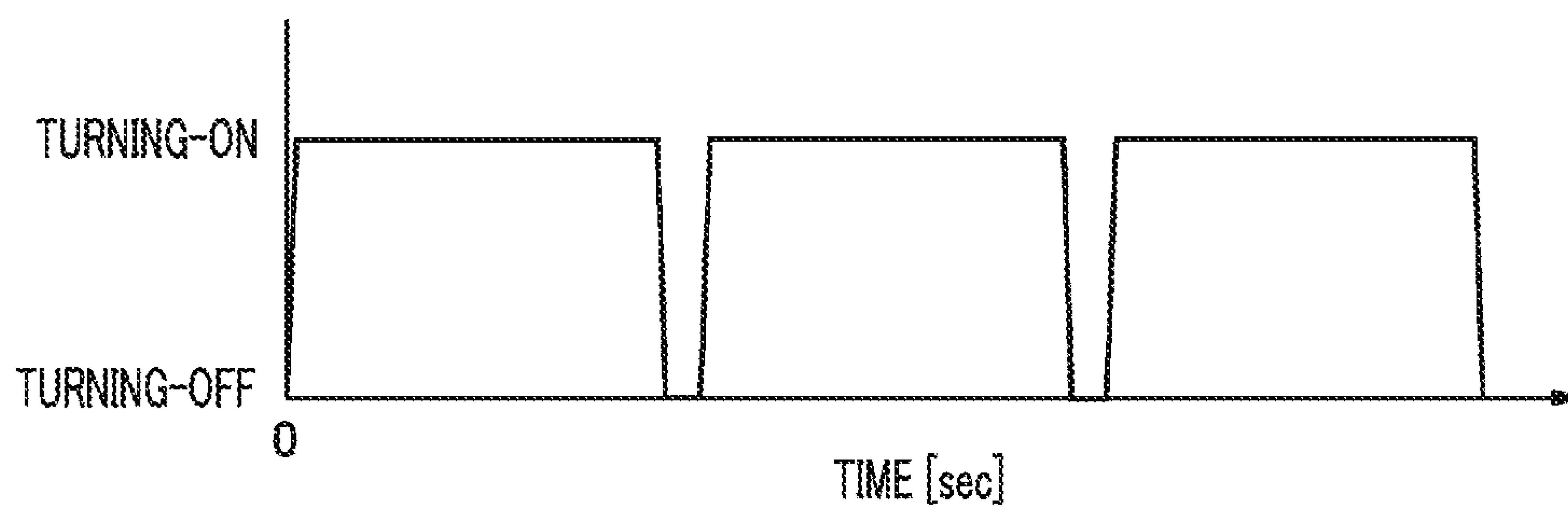


FIG. 12

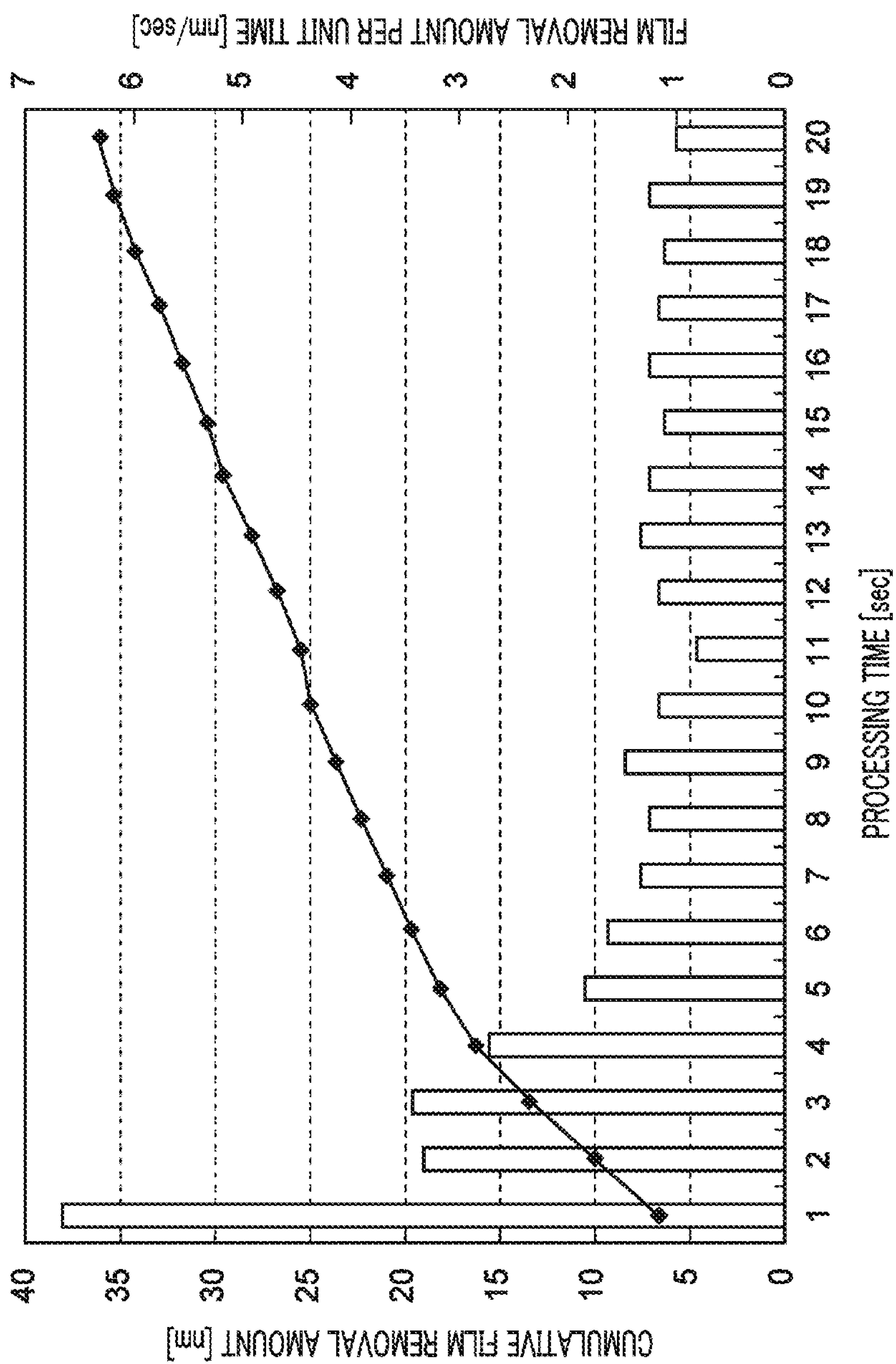


FIG. 13

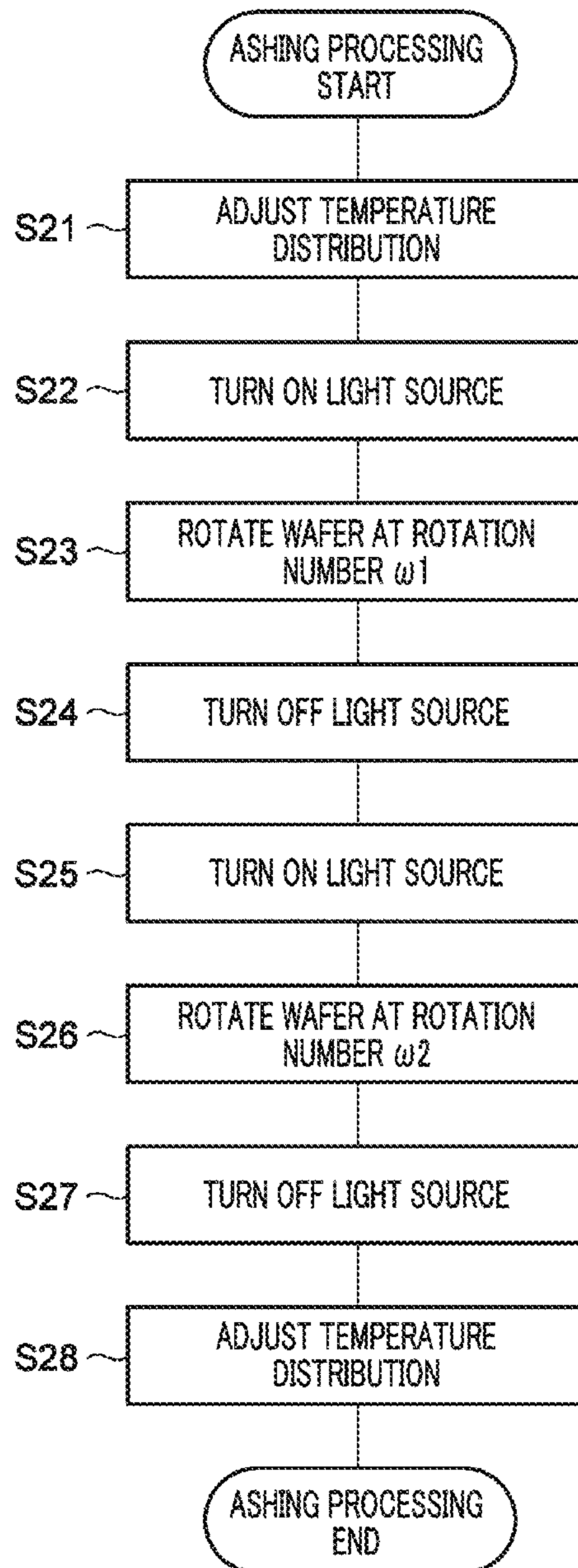


FIG. 14A

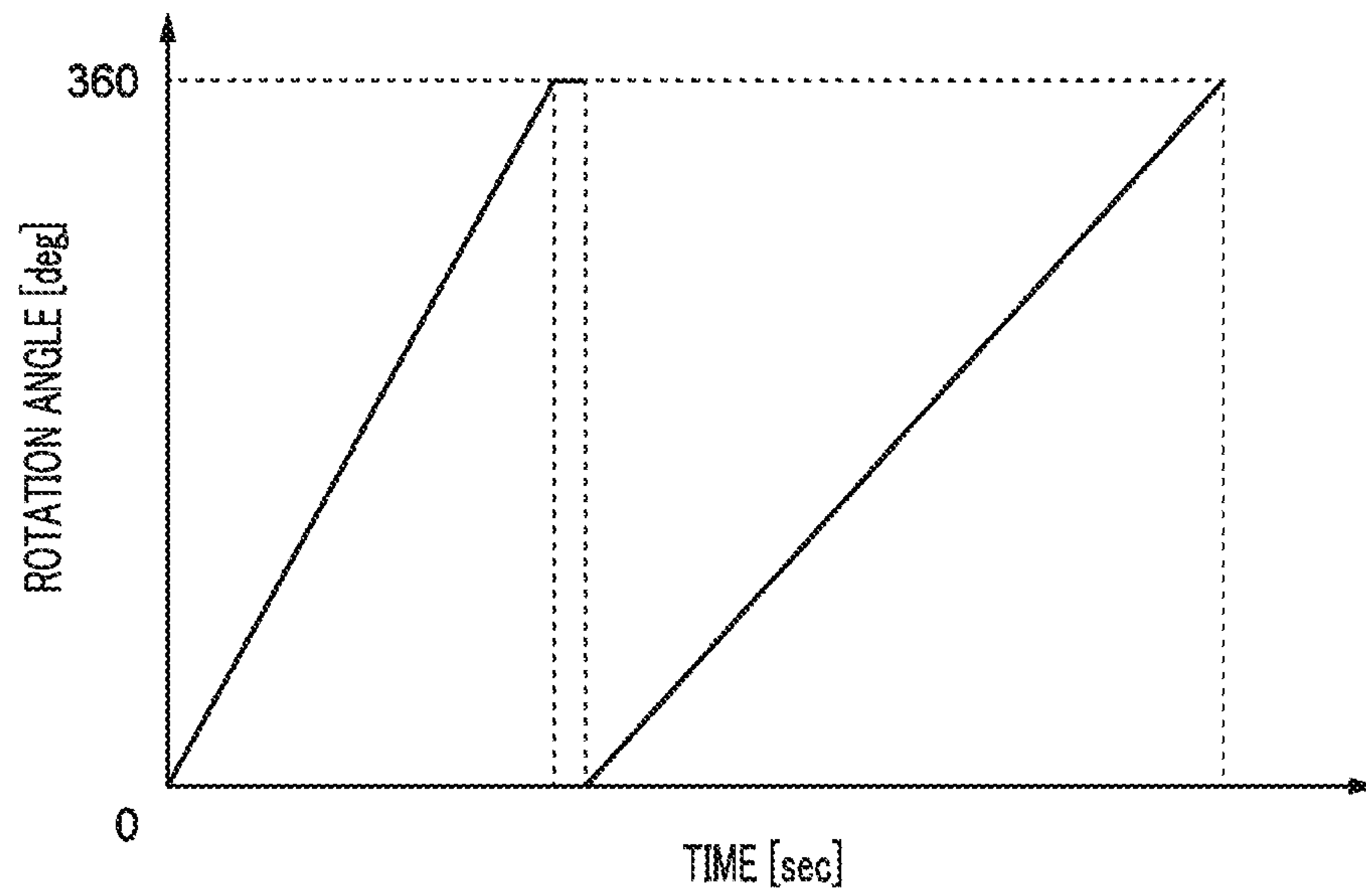


FIG. 14B

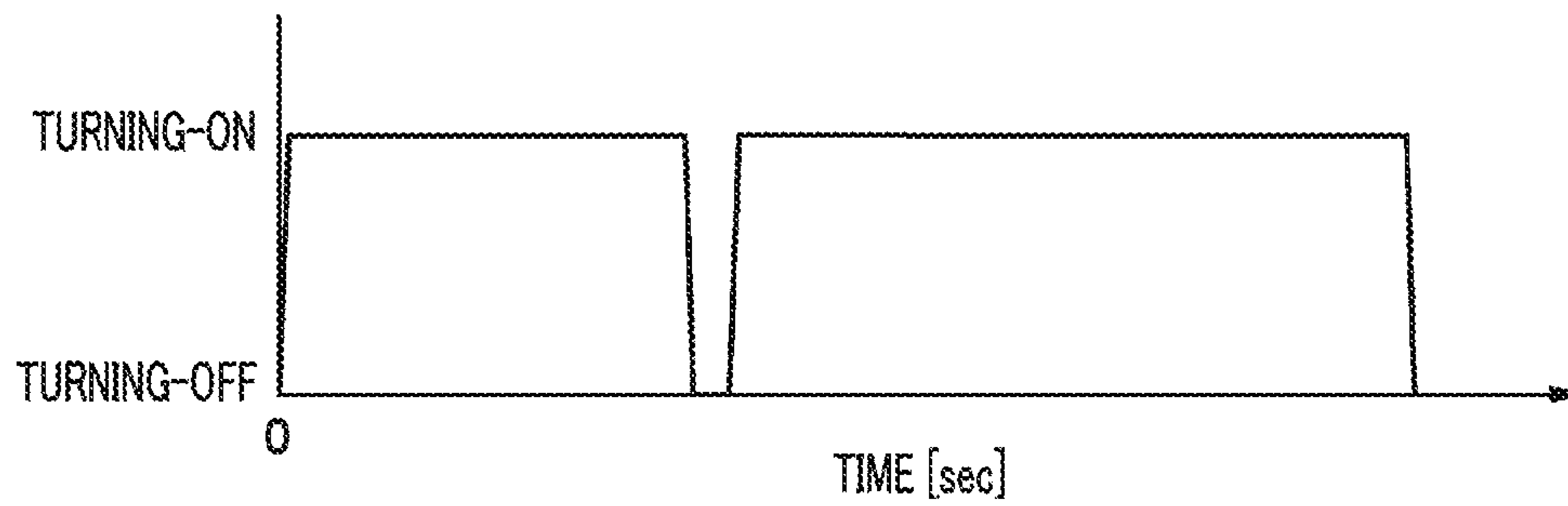


FIG. 15A

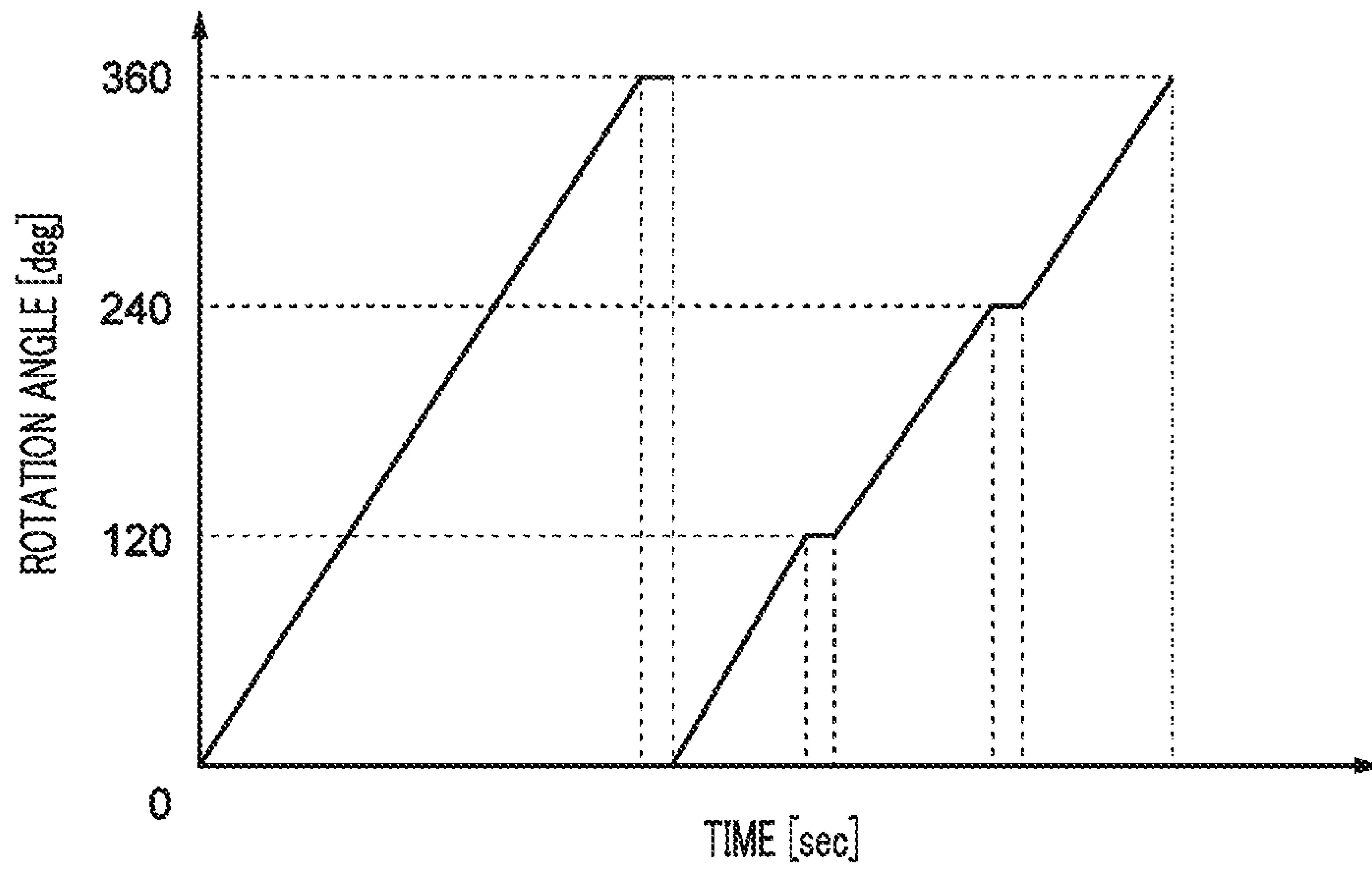


FIG. 15B

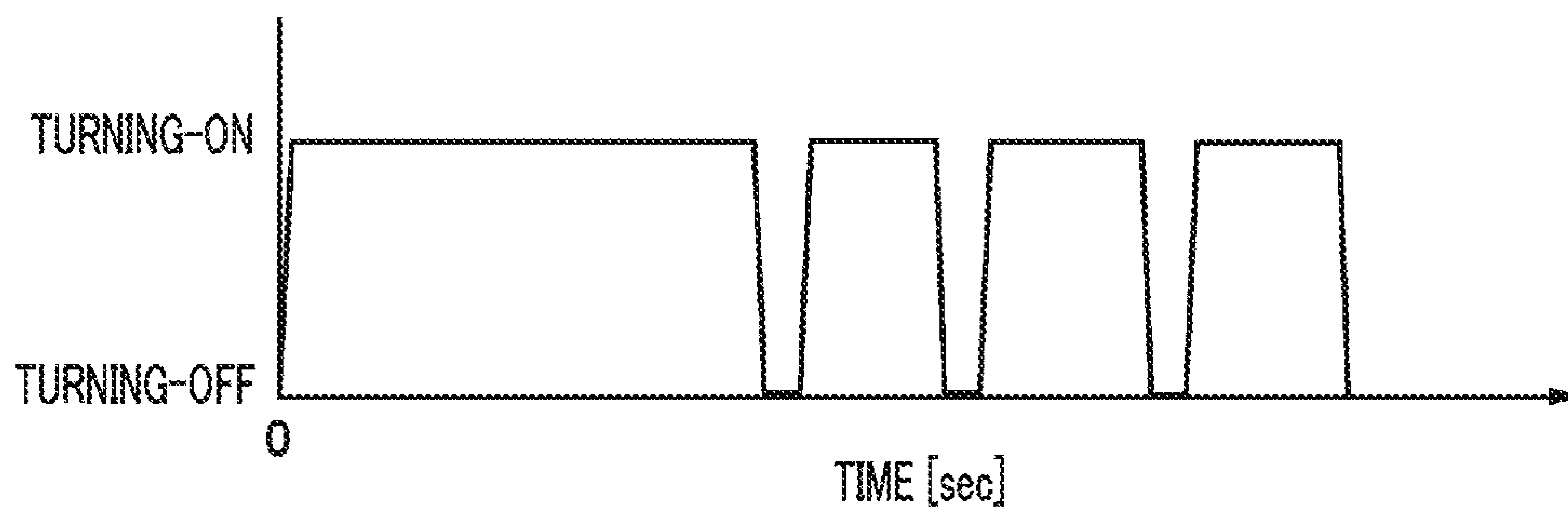


FIG. 16A

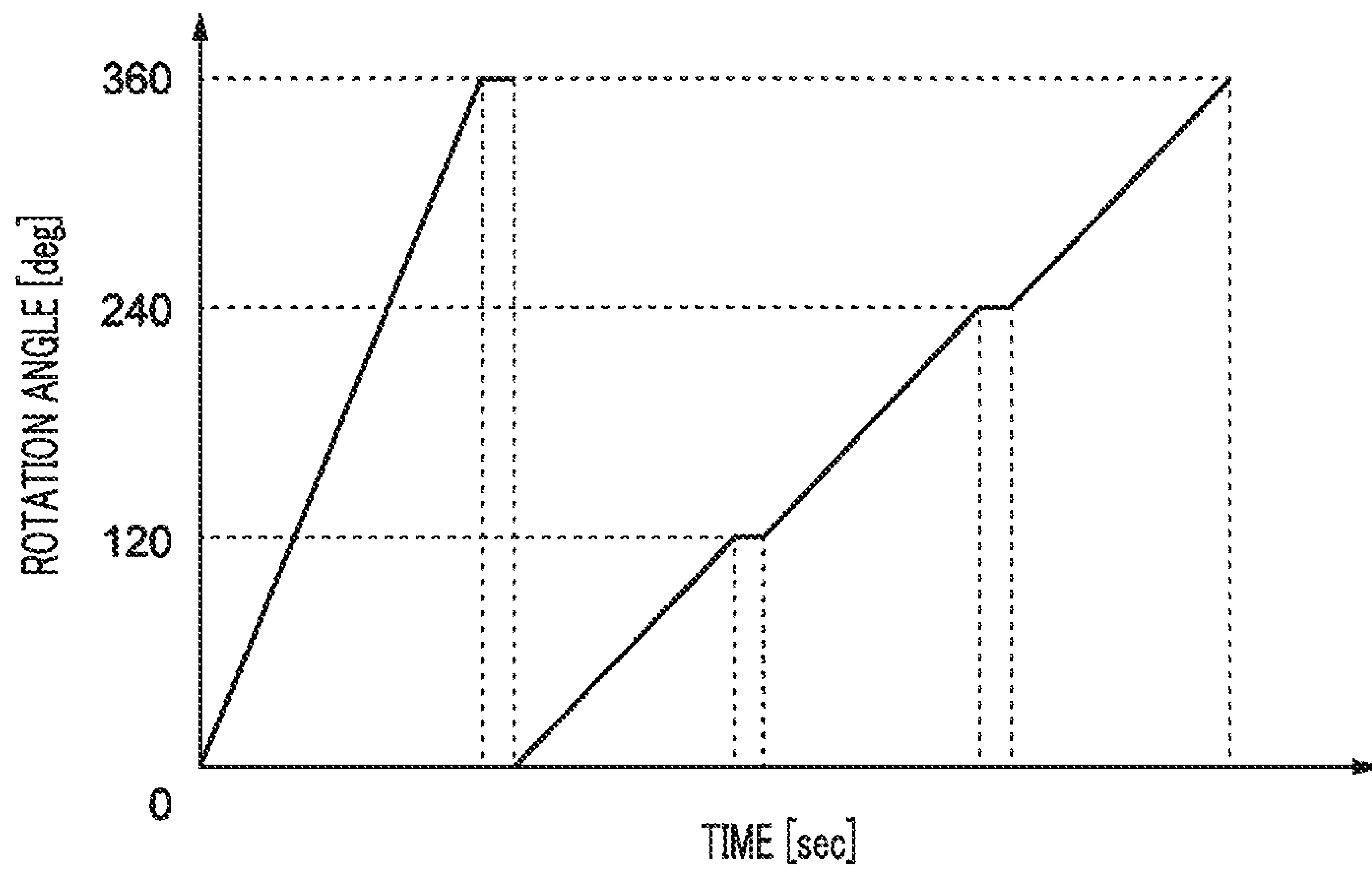


FIG. 16B

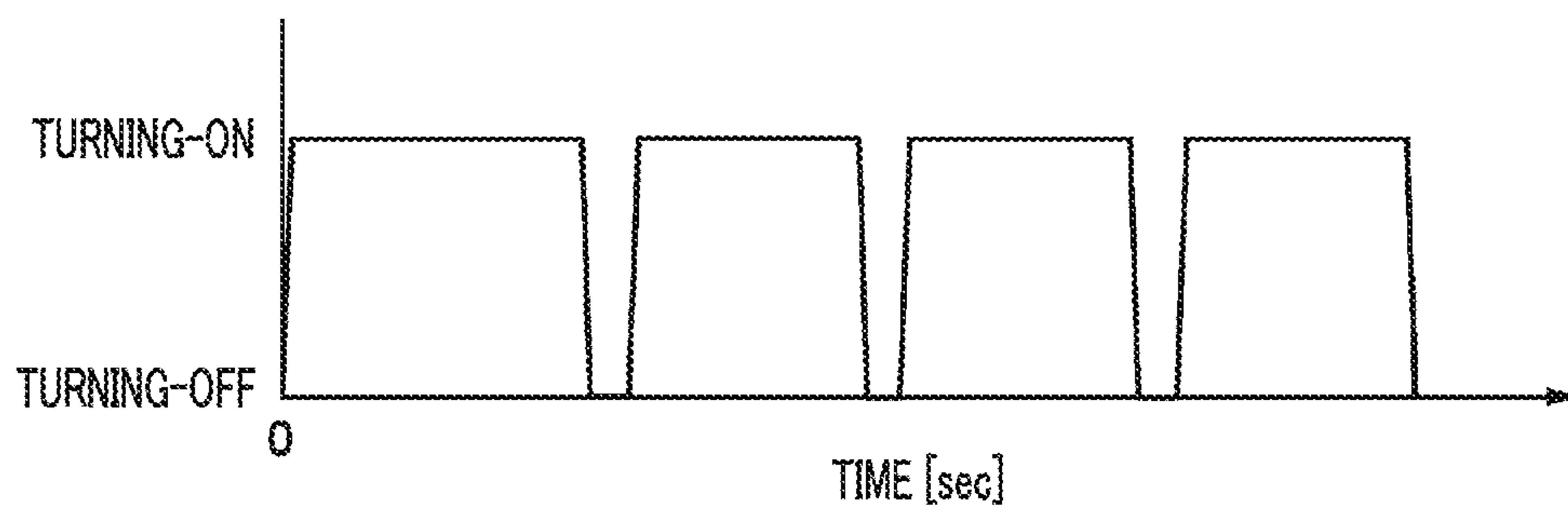


FIG. 17A

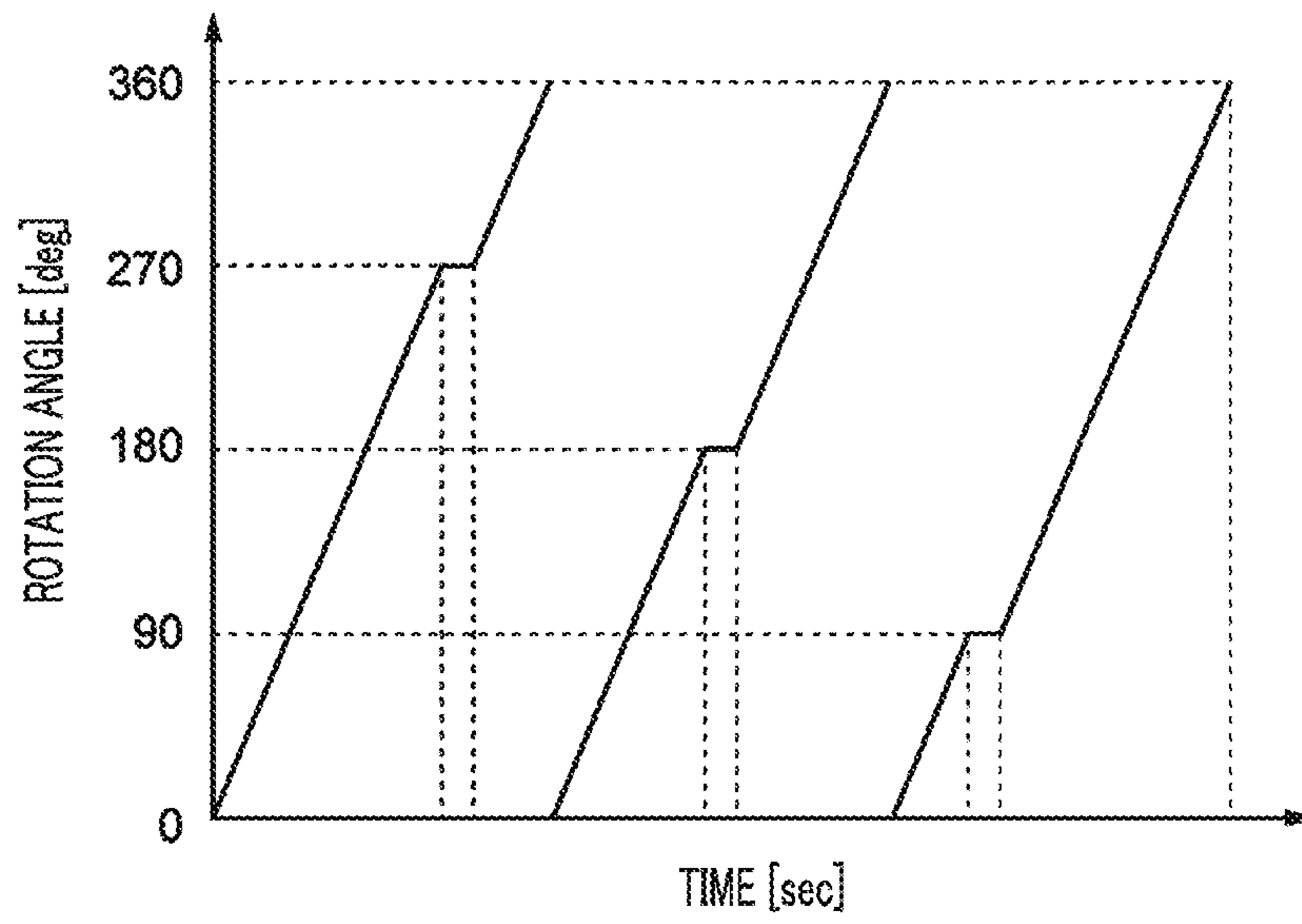


FIG. 17B

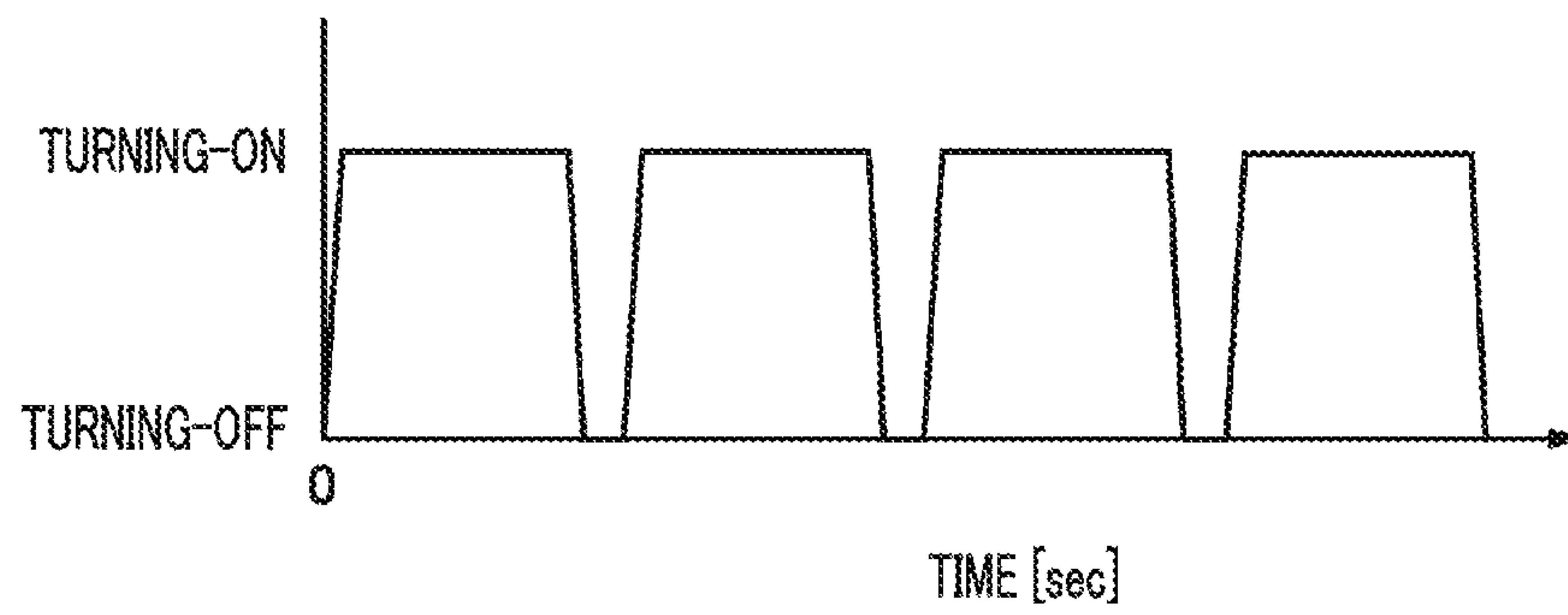


FIG. 18A

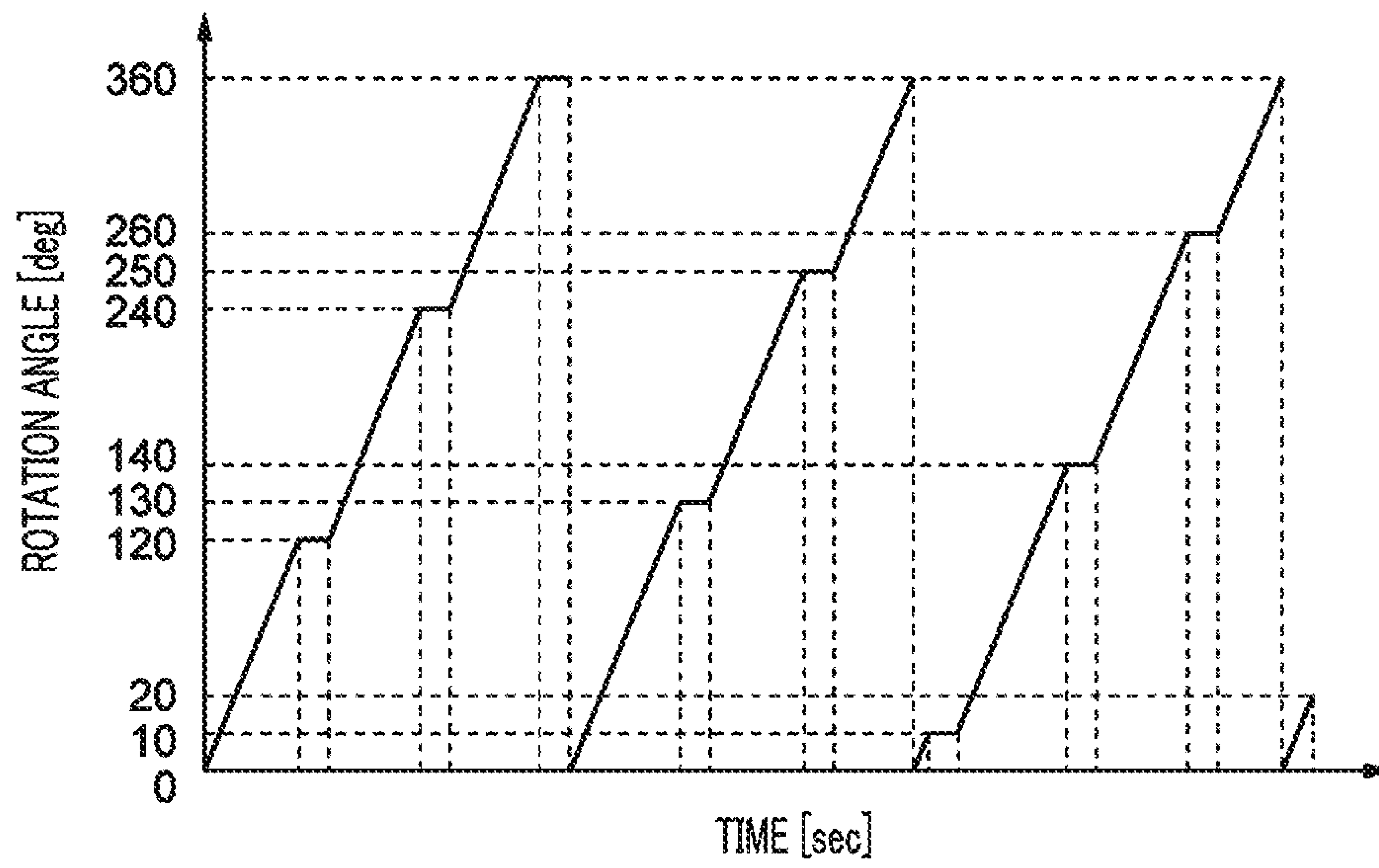
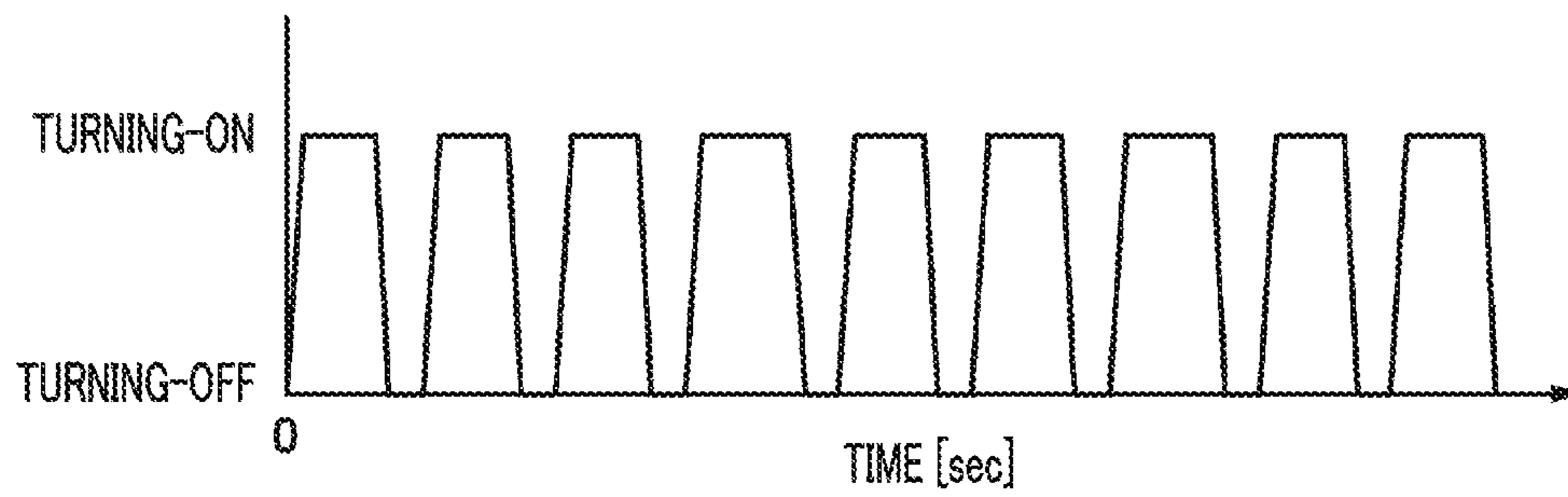


FIG. 18B



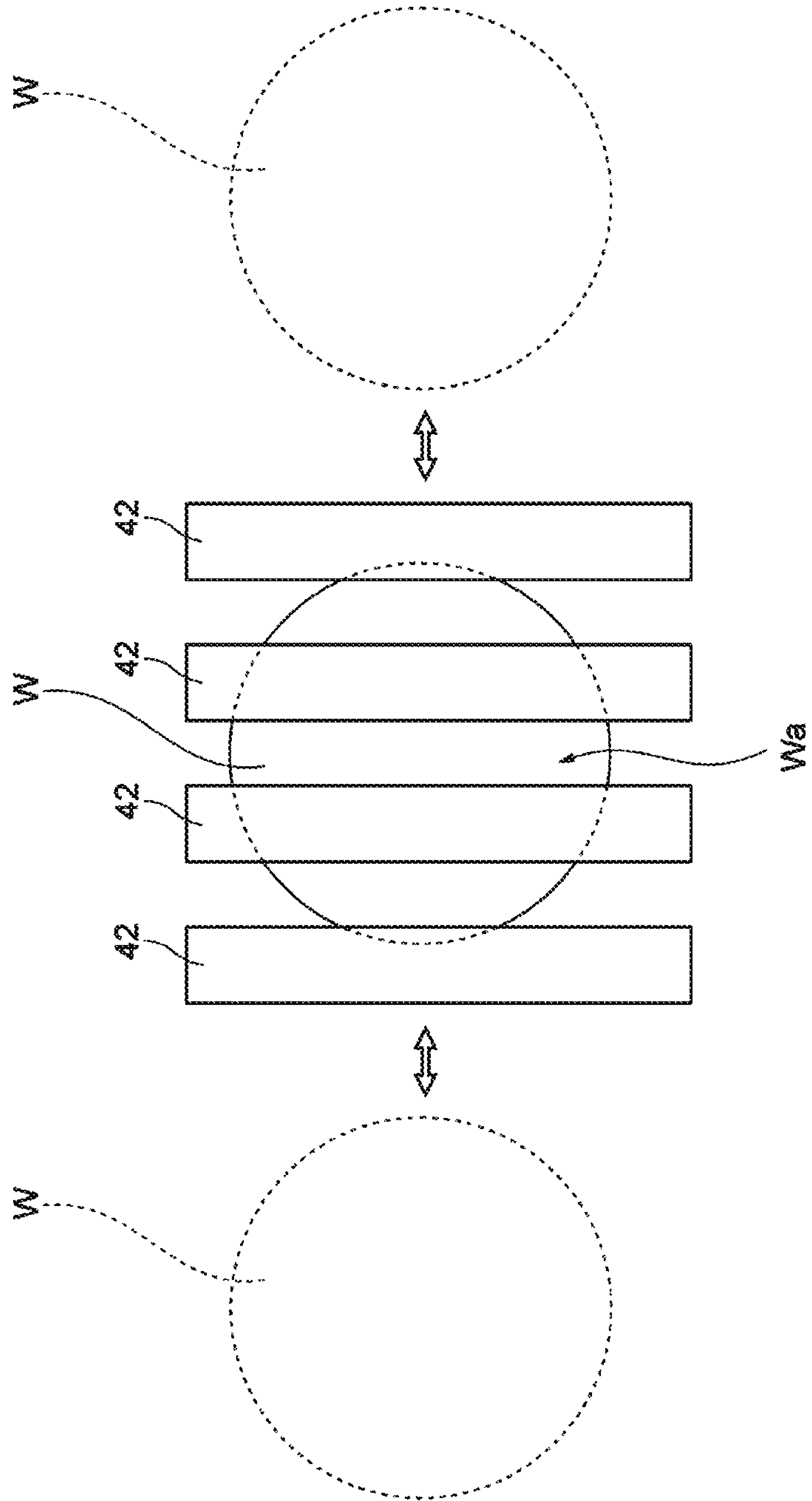


FIG. 19

FIG. 20A

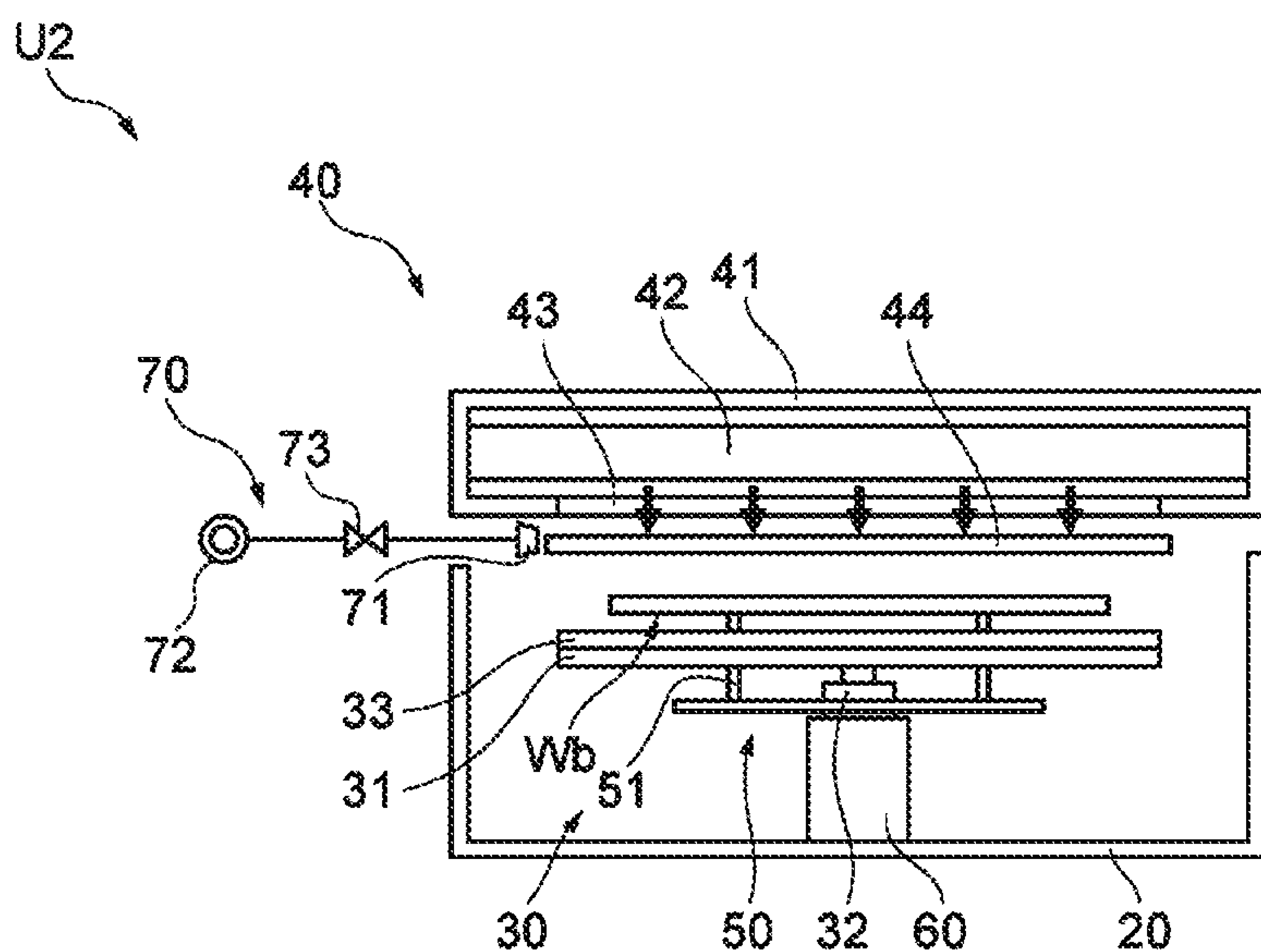


FIG. 20B

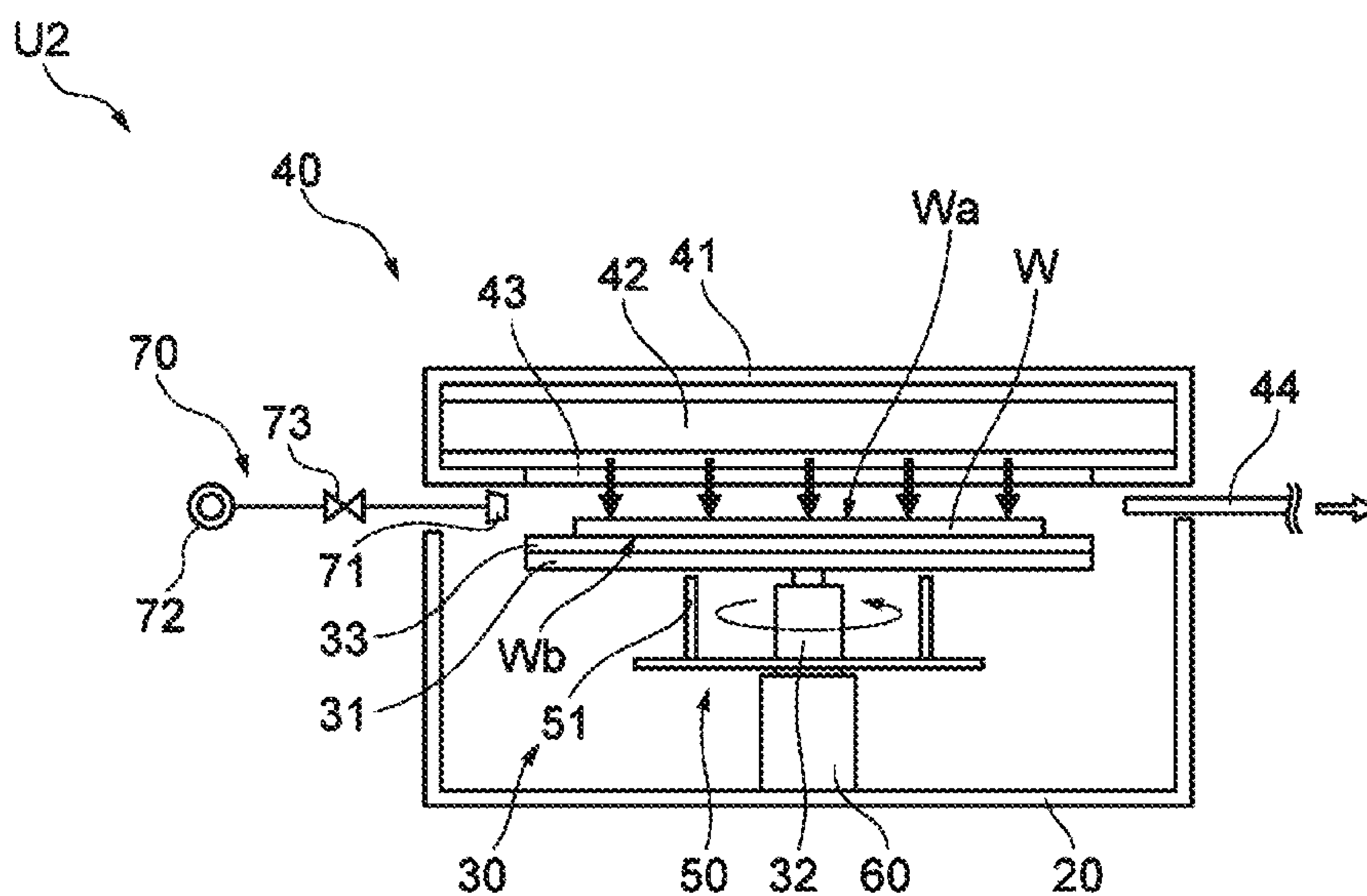


FIG. 21A

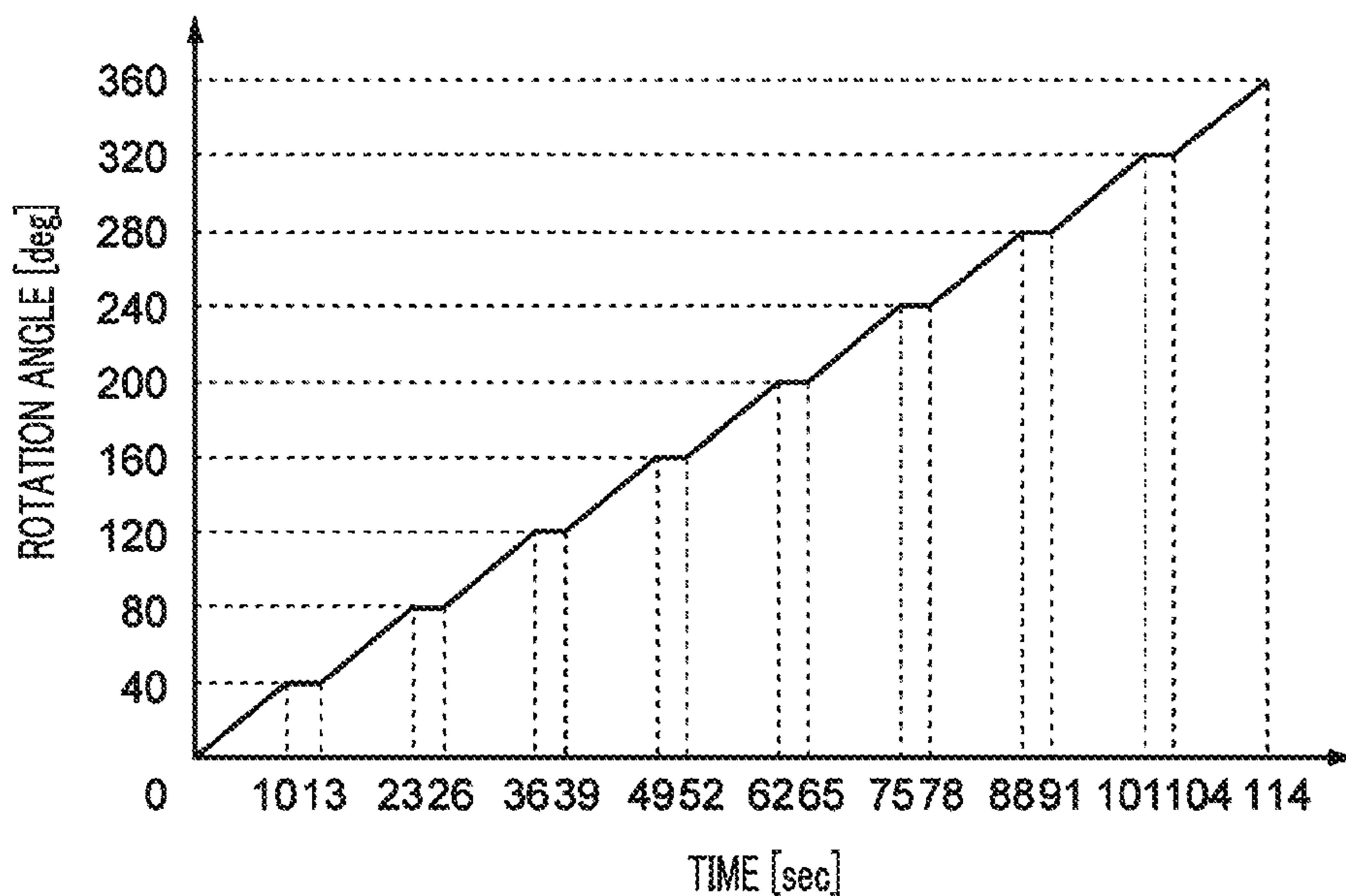


FIG. 21B

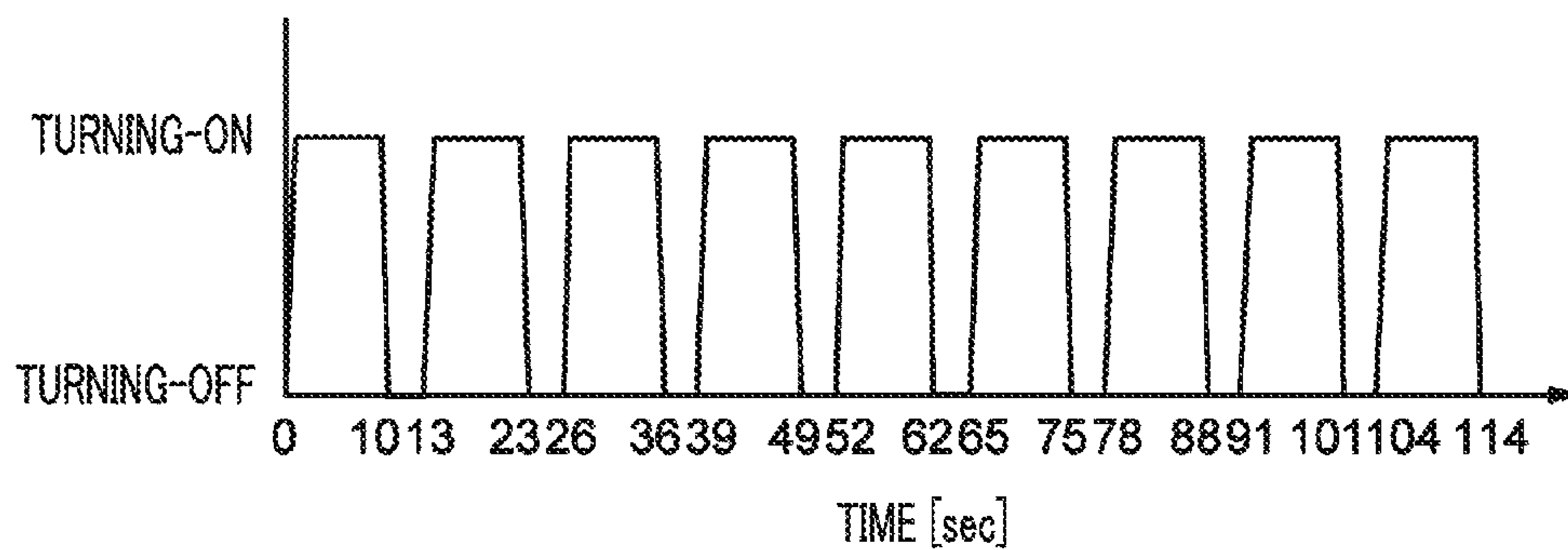


FIG. 22A

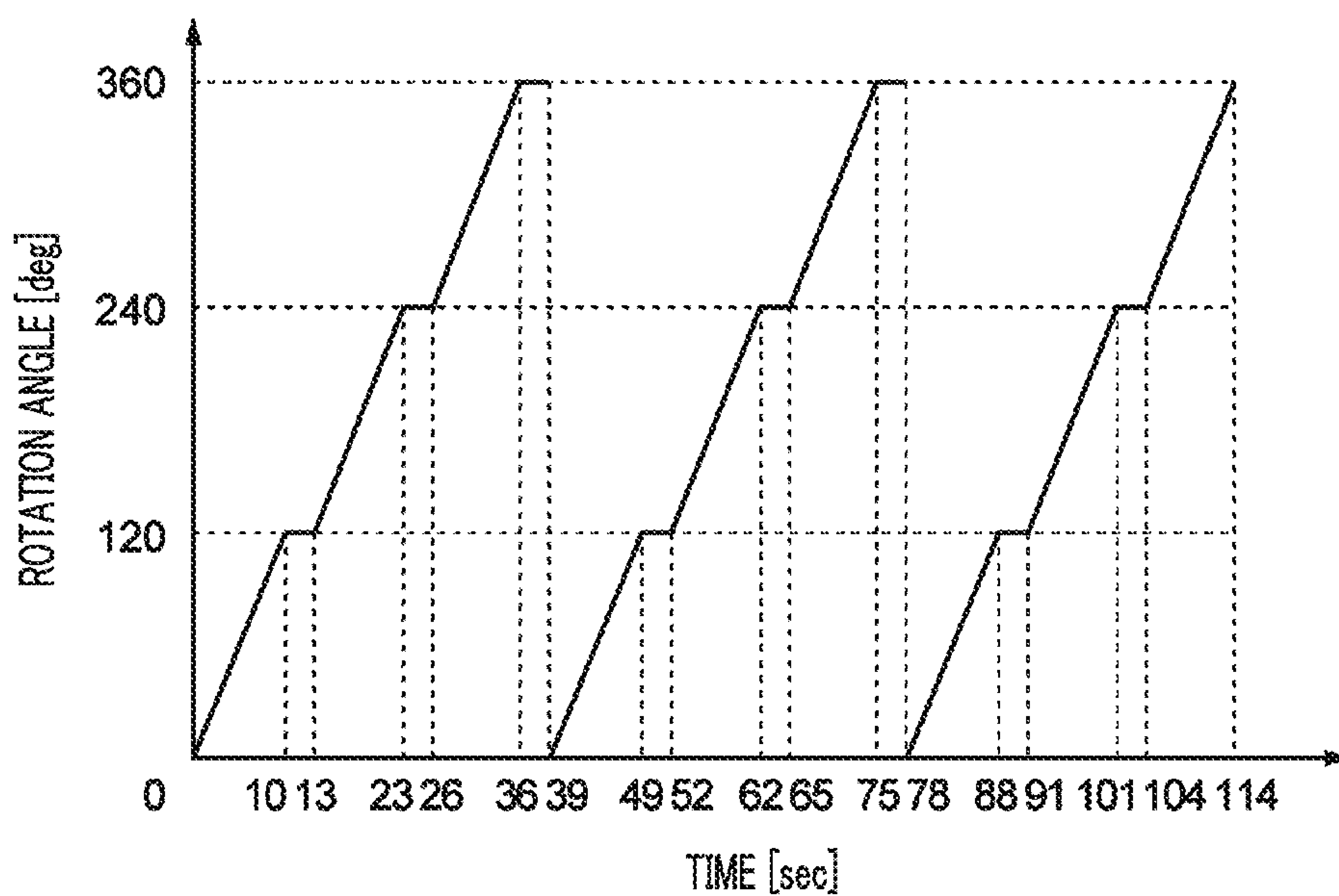


FIG. 22B

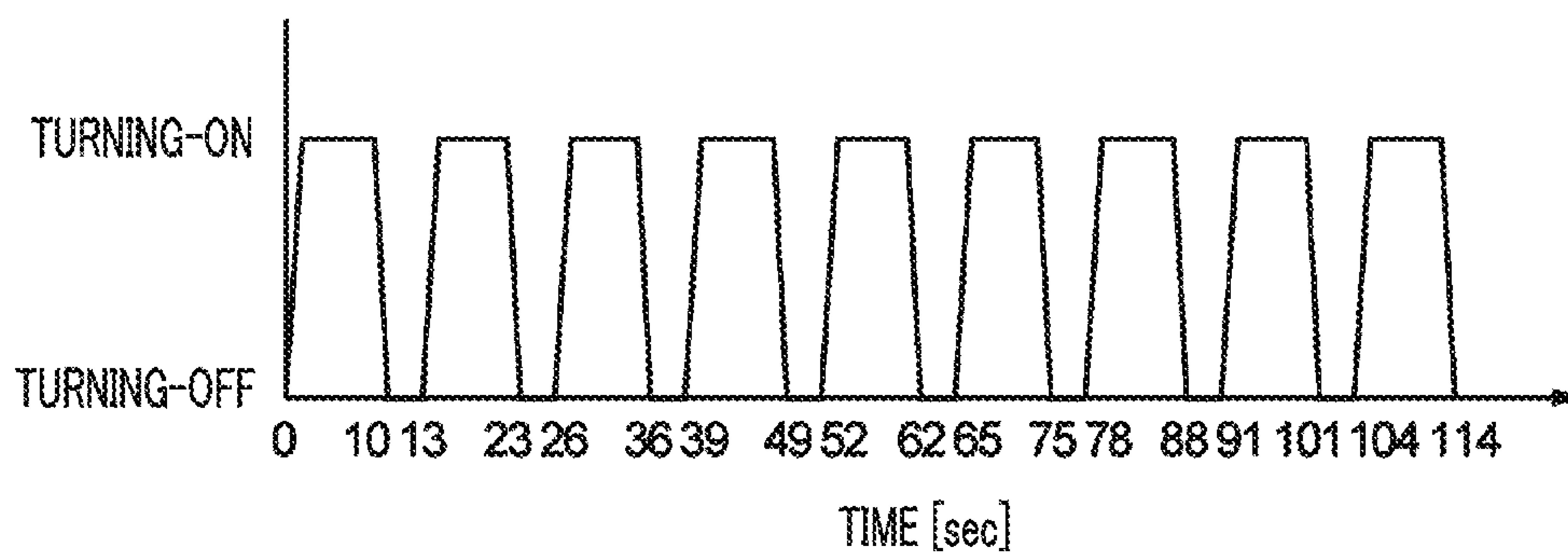


FIG. 23A

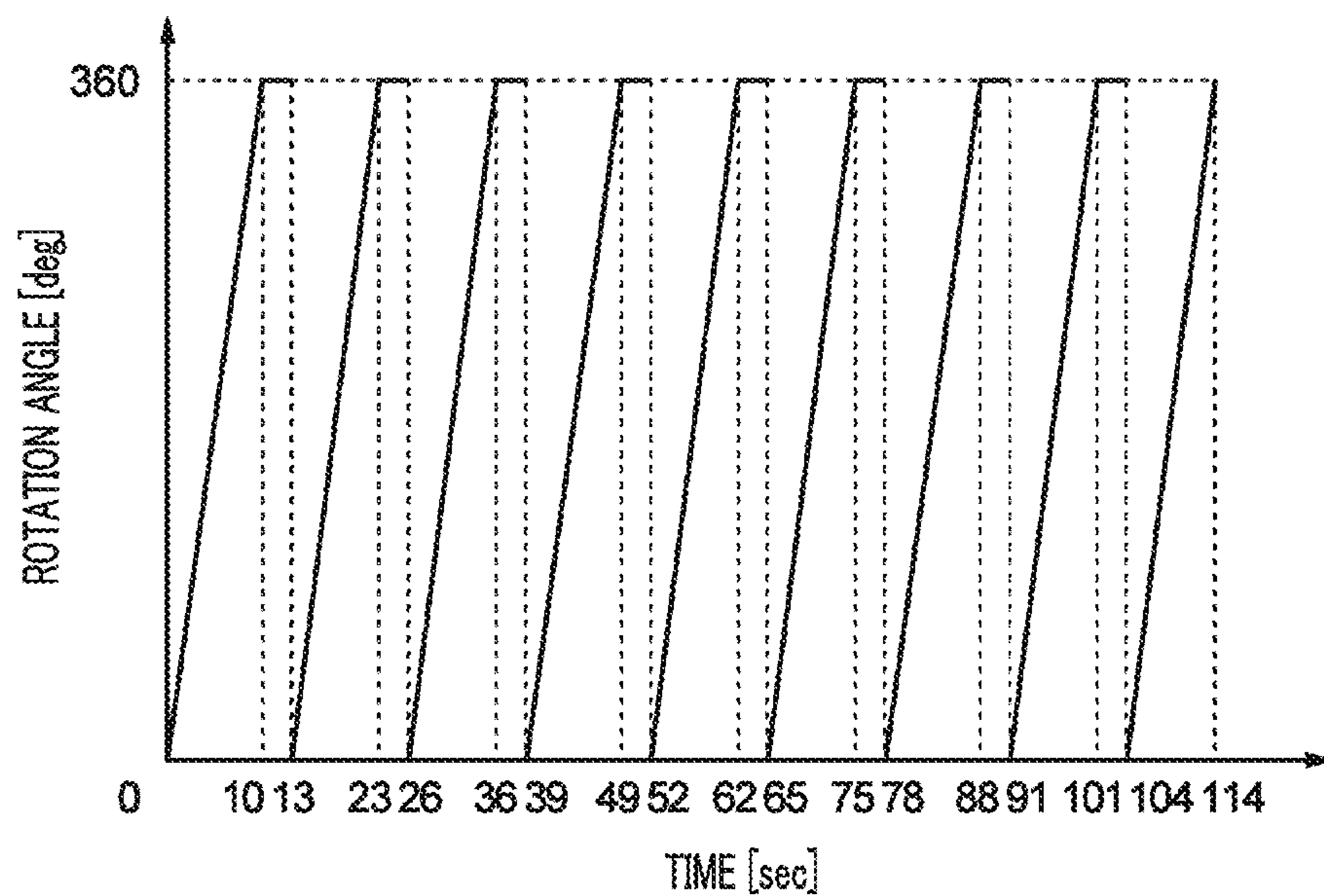


FIG. 23B

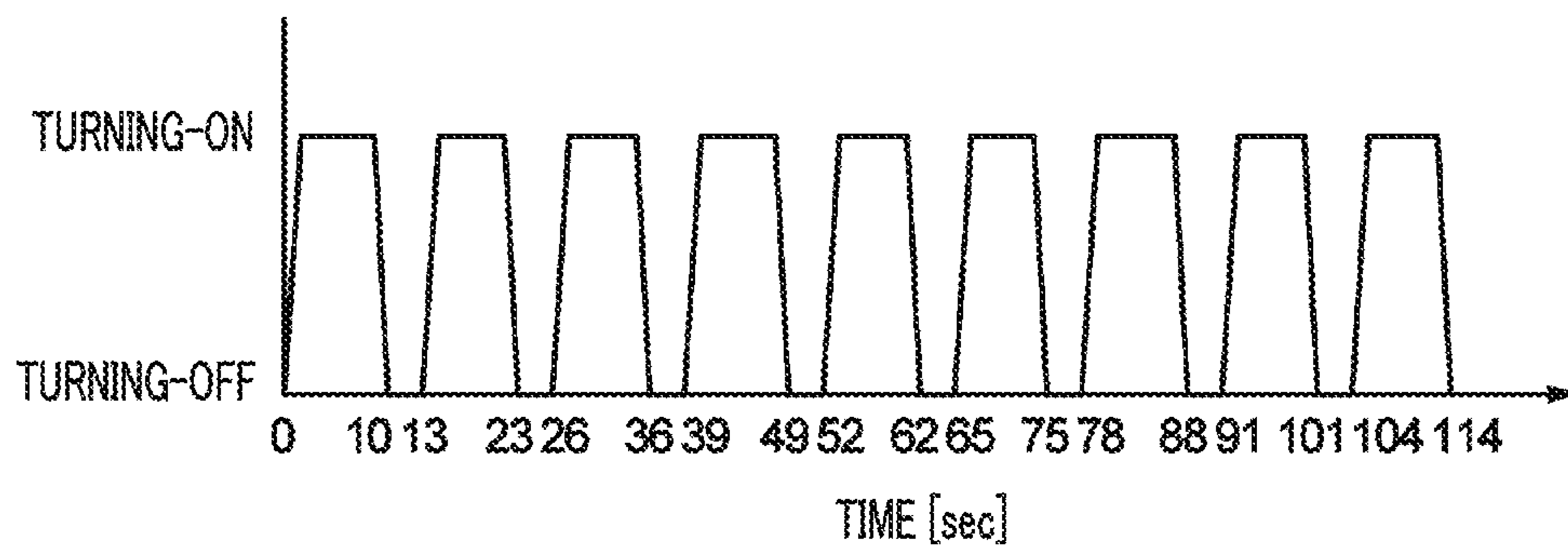


FIG. 24A

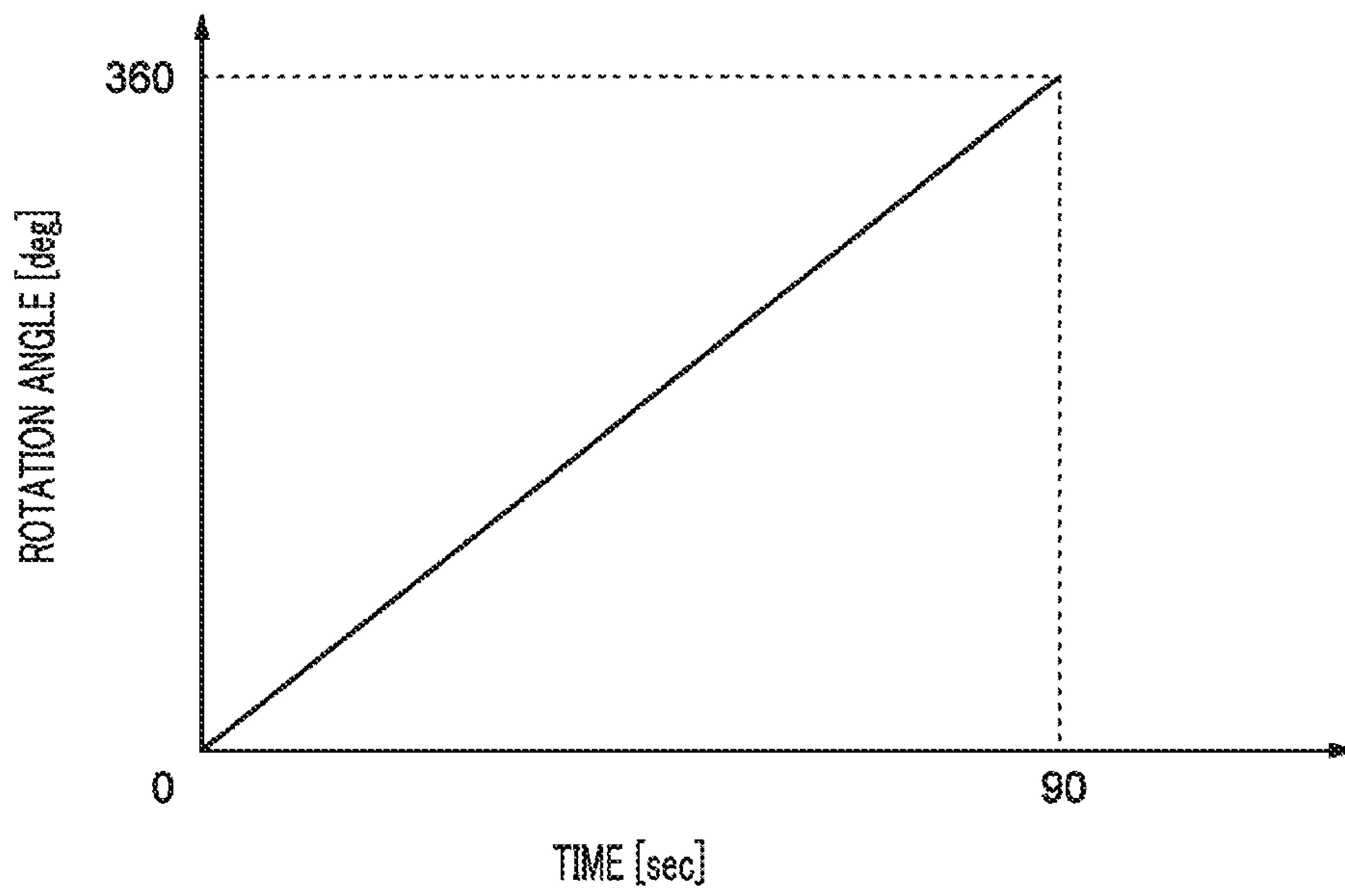


FIG. 24B

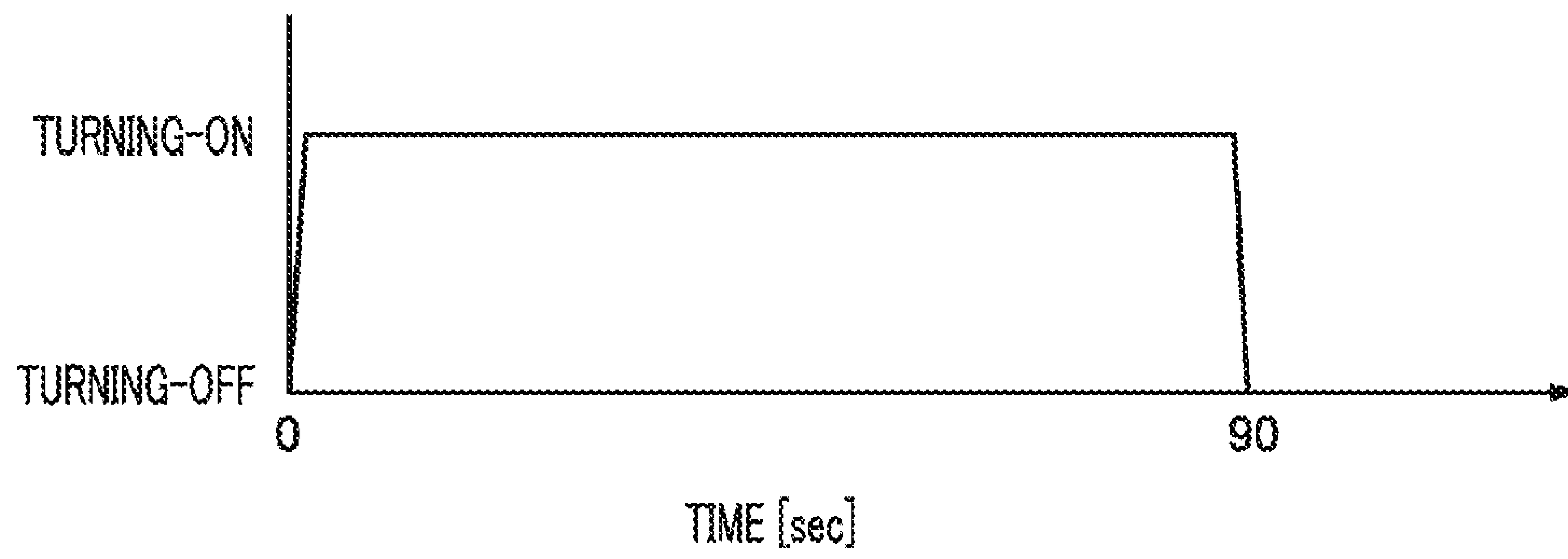


FIG. 25A

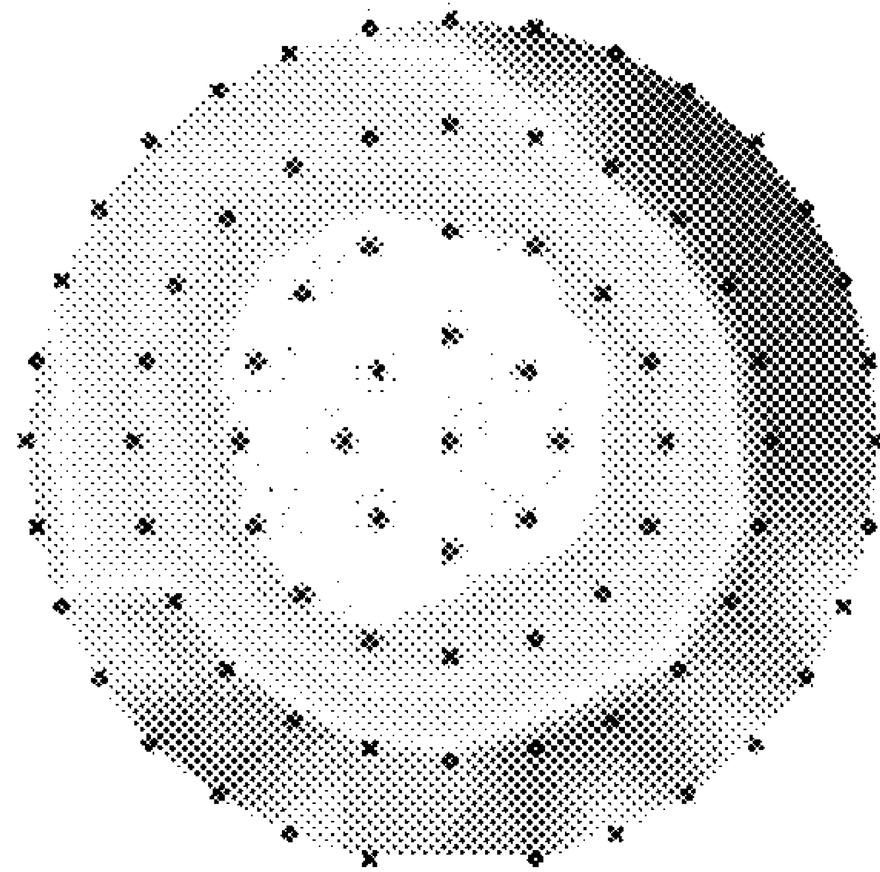


FIG. 25B

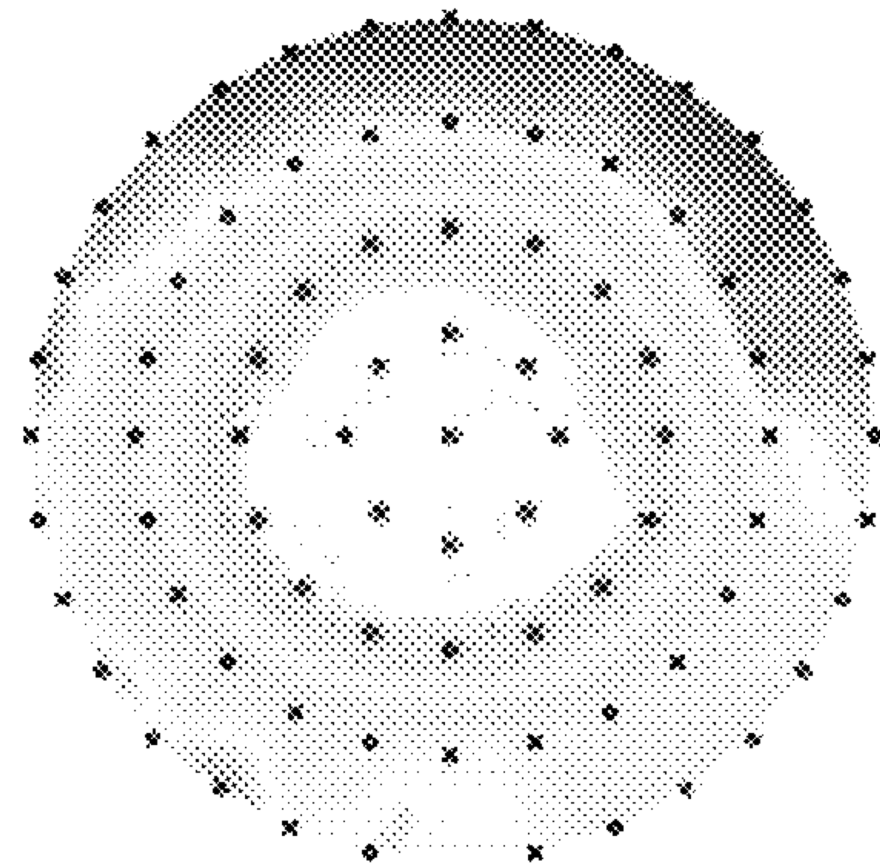


FIG. 26A

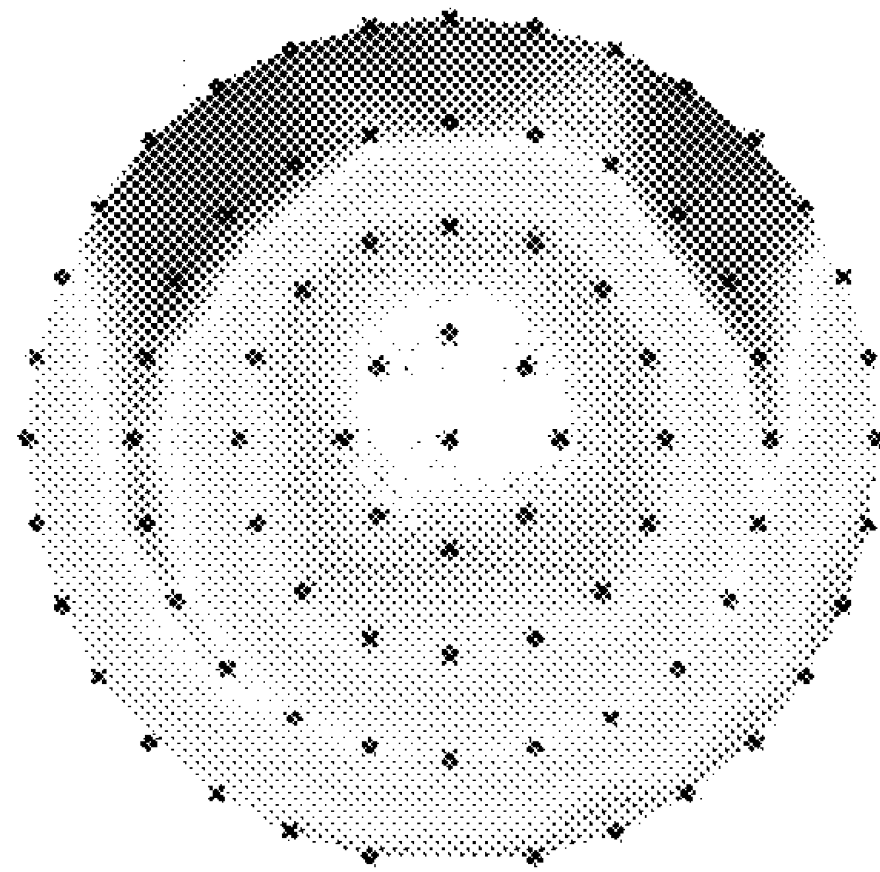
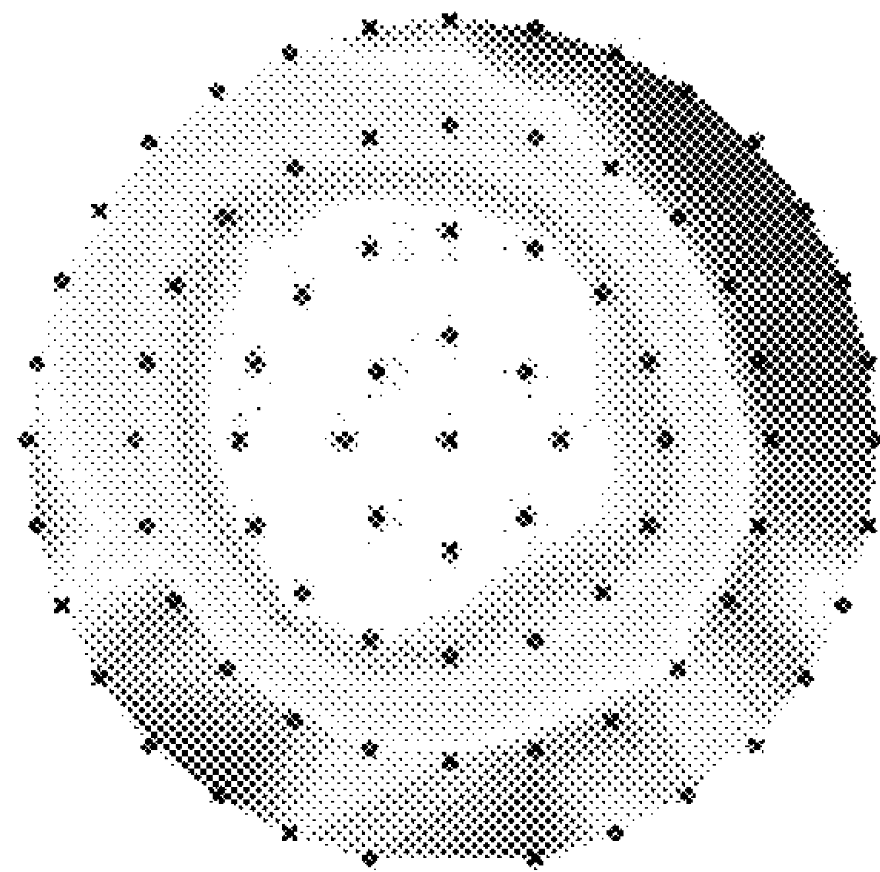


FIG. 26B



ASHING APPARATUS, ASHING METHOD AND RECORDING MEDIUM

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of Japanese Patent Application No. 2018-012256 filed on Jan. 29, 2018, the entire disclosures of which are incorporated herein by reference.

TECHNICAL FIELD

The various aspects and embodiments described herein pertain generally to an ashing apparatus, an ashing method and a computer-readable recording medium.

BACKGROUND

Patent Document 1 discloses a substrate processing method. In this method, a substrate having a processing target film formed thereon is placed in a processing chamber under an oxygen-containing atmosphere having a gas flow velocity equal to or less than 10 cm/sec, and a part of an organic film is removed by irradiating an ultraviolet ray to the substrate.

Patent Document 1: Japanese Patent Laid-open Publication No. 2016-027617

SUMMARY

Exemplary embodiments provide an ashing apparatus, an ashing method and a computer-readable recording medium capable of improving, when ashing an organic film formed on a surface of a substrate, uniformity in a film removal amount by the ashing within the surface of the substrate.

Example 1

In an exemplary embodiment of an ashing apparatus, an ashing apparatus includes a light irradiating unit configured to irradiate, to a substrate having an organic film formed on a surface thereof, processing light for ashing the organic film; a posture changing unit configured to change a posture of the substrate with respect to the light irradiating unit by driving at least one of the substrate or the light irradiating unit; and a control unit. The control unit performs: a first processing of controlling the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a first posture to a second posture; and a second processing of controlling, after the first processing, the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture.

Through researches by the present inventors, however, it is found out that the beginning of the operation of the irradiating unit is not stable. That is, immediately after the processing light from the irradiating unit is turned on, there may exist some non-uniformity until the processing light comes into a normal state. For this reason, if the substrate is always at the same posture when the turning-on of the irradiating unit is begun, an adverse influence caused by the non-stable beginning of the operation of the irradiating unit may be concentrated to a preset place of the substrate. Specifically, the ashing may not progress sufficiently at this preset place of the substrate, and there may be caused non-uniformity in the film removal amount of the protective film. According to the ashing apparatus of Example 1, however, in the first processing and the second processing performed subsequently, the postures of the substrate are all different whenever the turning-on operation of the irradiating unit is begun. Therefore, the adverse influence caused by the non-stable beginning of the operation of the irradiating unit is suppressed from being concentrated to the preset place of the substrate. Therefore, when ashing the organic film formed on the front surface of the substrate, the uniformity in the film removal amount by the ashing within the surface of the substrate can be improved.

Example 2

In another exemplary embodiment of the ashing apparatus, an ashing apparatus includes a light irradiating unit configured to irradiate, to a substrate having an organic film formed on a surface thereof, processing light for ashing the organic film; a posture changing unit configured to change a posture of the substrate with respect to the light irradiating unit by driving at least one of the substrate or the light irradiating unit; and a control unit. The control unit performs: a first processing as an initial processing of controlling the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate from the light irradiating unit while moving the substrate with respect to the light irradiating unit at a first speed; and a second processing as a subsequent processing of controlling, after the first processing, the posture changing unit and the light irradiating unit to irradiate the processing light to the surface of the substrate from the light irradiating unit while moving the substrate with respect to the light irradiating unit at a second speed lower than the first speed.

So far, it is believed that the film removal amount by the ashing remains substantially same regardless of a lapse of time. According to researches by the present inventors, however, it is found out that the film removal amount by the ashing is largest at the beginning of the ashing processing and gradually decreases with a lapse of a processing time. According to the ashing apparatus of Example 2, the moving speed of the substrate in the first processing as the initial processing is set to be higher than the moving speed of the substrate in the second processing as the subsequent processing. Accordingly, in the initial processing in which the film removal amount per unit time (hereinafter, sometimes referred to as "removing rate") is large, a larger area of the substrate is ached. Therefore, concentration of the adverse influence in the initial processing to the preset place of the substrate can be suppressed. As a result, when ashing the organic film formed on the surface of the substrate, it is possible to improve the uniformity in the film removal amount by the ashing within the surface of the substrate.

Example 3

In the ashing apparatus of Example 2, the second processing comprises: irradiating the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a first posture to a second posture at the second speed; and irradiating the processing light to the surface of the substrate from the light irradiating unit while

changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture at the second speed. In this case, in the second processing as the subsequent processing, the same effect as that of Example 1 is achieved.

Example 4

In the ashing apparatus of any one of Examples 1 to 3, the posture changing unit may be configured to rotate the substrate.

Example 5

In the ashing apparatus of Example 4, a rotation number of the substrate in the first processing may be set to be in a range from 1 rpm to 100 rpm. In this case, in the first processing, the substrate is rotated at a relatively high rotation number. In the first processing, the removing rate tends to be high, as compared to that of the second processing. Thus, in the first processing where the removing rate is relatively high, a larger area of the substrate is ached. Hence, the uniformity in the film removal amount by the ashing within the surface of the substrate can be further improved.

Example 6

The ashing apparatus of any one of Examples 1 to 5 may further include a distance changing unit configured to change a gap between the substrate and the light irradiating unit. The control unit controls the distance changing unit to set a size of the gap in the second processing to be different from a size of the gap in the first processing. In case that an oxygen-containing gas continuously flows around the substrate in the ashing processing, the smaller the gap is, the more difficult it is for the gas to flow in the gap, so that the removing rate tends to be decreased. Meanwhile, the larger the gap is, the easier it is for the gas to flow in the gap, so that the removing rate tends to be increased. In view of this, by setting the gap to be smaller in the first processing where the removing rate tends to be large as compared to that of the second processing, the uniformity in the film removal amount by the ashing within the surface of the substrate can be further improved. Further, if the flow of the oxygen-containing gas is not generated around the substrate in the ashing processing, the larger the gap is, the more difficult it is for the processing light to reach the substrate from the irradiating unit. As a result, the removing rate tends to be reduced. Meanwhile, the smaller the gap is, the easier it is for the processing light from the irradiating unit to reach the substrate, so that the removing rate tends to be increased. Thus, by setting the gap to be larger in the first processing in which the removing rate tends to be high as compared to that of the second processing, the uniformity in the film removal amount by the ashing within the surface of the substrate can be further improved.

Example 7

In the ashing apparatus of any one of Examples 1 to 6, the control unit may further perform a third processing of controlling the light irradiating unit to turn-on, when a preset time elapses after the processing light from the light irradiating unit is turned off, the light irradiating unit such that the processing light is not irradiated to the surface of the substrate, and then, irradiate the processing light to the surface of the substrate. In this case, the processing light from the light irradiating unit is irradiated to the surface of the substrate after a temperature of the light irradiating unit is stabilized. Therefore, a variation of the removing rate that may be caused by a temperature variation of the light irradiating unit is suppressed. Thus, it is possible to further improve the uniformity in the film removal amount by the ashing within the surface of the substrate. Further, if a preset time period supposed to elapse after the light irradiating unit is turned off is previously known, the light irradiating unit may be turned on before the preset time passes by. In such a case, by turning off the processing light again within a predetermined time immediately before the third processing to allow the uniformity in the film removal amount within the surface of the substrate to fall within an allowable range, it is possible to achieve both improvement of the uniformity in the film removal amount within the surface of the substrate and the reduction of the power consumption caused by the turning-on operation of the light irradiating unit.

Example 8

In an exemplary embodiment of an ashing method, an ashing method includes a first process of irradiating, to a surface of a substrate having an organic film formed on the surface thereof, processing light for ashing the organic film from a light irradiating unit while changing a posture of the substrate with respect to the light irradiating unit from a first posture to a second posture; and a second process of irradiating, after the first process, the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture. In this case, the same effect as that of the ashing apparatus of Example 1 is achieved.

Example 9

In another exemplary embodiment of the ashing method, an ashing method includes a first process as an initial process of irradiating, to a surface of a substrate having an organic film formed on the surface thereof, processing light for ashing the organic film from a light irradiating unit while moving the substrate with respect to the light irradiating unit at a first speed; and a second process as a subsequent process of irradiating, after the first process, the processing light to the surface of the substrate from the light irradiating unit while moving the substrate with respect to the light irradiating unit at a second speed lower than the first speed. In this case, the same effect as that of the ashing apparatus of Example 2 is achieved.

Example 10

In the ashing method of Example 9, the second process may include irradiating the processing light to the surface of the substrate from the light irradiating unit while changing a posture of the substrate with respect to the light irradiating unit from a first posture to a second posture at the second speed; and irradiating the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture at the second speed. In this case, the same effect as that of the ashing apparatus of Example 3 is achieved.

Example 11

In the ashing method of any one of Examples 8 to 10, the substrate may be rotated with respect to the light irradiating

unit. In this case, the same effect as that of the ashing apparatus of Example 4 is achieved.

Example 12

In the ashing method of Example 9, a rotation number of the substrate in the first process may be set to be in a range from 1 rpm to 100 rpm. In this case, the same effect as that of the ashing apparatus of Example 5 is achieved.

Example 13

In the ashing method of any one of Examples 8 to 12, a gap between the substrate and the light irradiating unit in the second process may be set to be different from the gap between the substrate and the light irradiating unit in the first process. In this case, the same effect as that of the ashing apparatus of Example 6 is achieved.

Example 14

The ashing method of any one of Examples 8 to 13 may further include a third process of turning-on, when a preset time elapses after the processing light from the light irradiating unit is turned off or when a temperature of the light irradiating unit after the processing light from the light irradiating unit is turned off is equal to or less than a preset value, the light irradiating unit such that the processing light is not irradiated to the surface of the substrate, and then, irradiating the processing light to the surface of the substrate. In this case, the same effect as that of the ashing apparatus of Example 7 is achieved.

Example 15

There is provided a computer-readable recording medium having stored thereon computer-executable instructions that, in response to execution, cause an ashing apparatus to perform the ashing method as described in any one of Examples 8 to 14. In this case, the same effect as that of the ashing method of any one of Examples 8 to 14 is achieved. In the present disclosure, the computer-readable recording medium includes a non-transitory computer recording medium (e.g., various kinds of main memory devices or auxiliary memory devices) and a transmission signal (transitory computer recording medium) (e.g., a data signal that can be provided via a network).

According to the ashing apparatus, the ashing method and the computer-readable recording medium of the present disclosure, when ashing the organic film formed on the surface of the substrate, the uniformity in the film removal amount by the ashing within the surface of the substrate can be improved.

The foregoing summary is illustrative only and is not intended to be any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

In the detailed description that follows, embodiments are described as illustrations only since various changes and modifications will become apparent to those skilled in the art from the following detailed description. The use of the same reference numbers in different figures indicates similar or identical items.

FIG. **1** is a perspective view illustrating a substrate processing system;

FIG. **2** is a cross sectional view taken along a line II-II of FIG. **1**;

FIG. **3** is a diagram schematically illustrating a configuration of an ashing unit;

FIG. **4** is a top view schematically illustrating a heat plate;

FIG. **5** is a perspective view schematically illustrating an irradiating unit with a ceiling wall of a housing removed;

FIG. **6** is a top view schematically illustrating rotation of a wafer with respect to a light source;

FIG. **7** is a schematic diagram illustrating a hardware configuration of a controller;

FIG. **8** is a flowchart for describing a wafer processing sequence;

FIG. **9** is a flowchart for describing an example of an ashing processing sequence;

FIG. **10**A is a diagram for describing a carry-in/carry-out of a wafer into/from the ashing unit, and FIG. **10**B is a diagram for describing light irradiation to the wafer;

FIG. **11**A is a graph showing an example of a variation of a rotation angle of the wafer with a lapse of time, and FIG. **11**B is a graph showing an example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **12** is a graph showing a relationship between a wafer ashing processing time and a film removal amount per unit time and a relationship between the wafer ashing processing time and a cumulative film removal amount;

FIG. **13** is a flowchart for describing another example of the ashing processing sequence;

FIG. **14**A is a graph showing another example of a variation of a rotation angle of the wafer with a lapse of time;

FIG. **14**B is a graph showing another example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **15**A is a graph showing yet another example of a variation of a rotation angle of the wafer with a lapse of time;

FIG. **15**B is a graph showing yet another example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **16**A is a graph showing still yet another example of a variation of a rotation angle of the wafer with a lapse of time;

FIG. **16**B is a graph showing still yet another example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **17**A is a graph showing still yet another example of a variation of a rotation angle of the wafer with a lapse of time;

FIG. **17**B is a graph showing still yet another example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **18**A is a graph showing still yet another example of a variation of a rotation angle of the wafer with a lapse of time;

FIG. **18**B is a graph showing still yet another example of a variation of turning-on and turning-off of the light source with the lapse of time;

FIG. **19** is a top view schematically illustrating a state in which the wafer is moved with respect to the light source;

FIG. **20**A is a diagram for describing dummy irradiation and FIG. **20**B is a diagram for describing light irradiation to the wafer;

FIG. 21A is a graph showing a variation of a rotation angle of a wafer with a lapse of time in a first experimental example, and FIG. 21B is a graph showing a variation of turning-on and turning-off of the light source in the first experimental example;

FIG. 22A is a graph showing a variation of a rotation angle of a wafer with a lapse of time in a second experimental example, and FIG. 22B is a graph showing a variation of turning-on and turning-off of the light source in the second experimental example;

FIG. 23A is a graph showing a variation of a rotation angle of a wafer with a lapse of time in a third experimental example, and FIG. 23B is a graph showing a variation of turning-on and turning-off of the light source in the third experimental example;

FIG. 24A is a graph showing a variation of a rotation angle of a wafer with a lapse of time in a comparative example, and FIG. 24B is a graph showing a variation of turning-on and turning-off of the light source in the comparative example;

FIG. 25A is a diagram showing an in-surface distribution of a film removal amount in the first experimental example, and FIG. 25B is a diagram showing the in-surface distribution of the film removal amount in the second experimental example; and

FIG. 26A is a diagram showing the in-surface distribution of the film removal amount in the third experimental example, and FIG. 26B is a diagram showing the in-surface distribution of the film removal amount in the comparative example.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part of the description. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Furthermore, unless otherwise noted, the description of each successive drawing may reference features from one or more of the previous drawings to provide clearer context and a more substantive explanation of the current exemplary embodiment. Still, the exemplary embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein and illustrated in the drawings, may be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

It should be noted once again that the exemplary embodiments of the present disclosure are nothing more than examples, and the present disclosure is not limited to the following description. In the following description, parts having same elements or same functions will be assigned same reference numerals, and redundant description will be omitted.

[Configuration of Substrate Processing Apparatus]

A configuration of a substrate processing apparatus **1** will be explained with reference to FIG. **1** and FIG. **2**. The substrate processing apparatus **1** is configured to perform a processing of forming a coating film on a surface of a substrate by coating the surface of the substrate with a coating liquid of an organic material, a processing of hardening the coating film by heat treatment to use the coating film as a protective film (organic film) and a processing of smoothing a surface of the protective film by an aching processing. The substrate as a processing target may be, by way of example, but not limitation, a semiconductor wafer W. The protective film may be a hard mask of, by way of non-limiting example, spin on carbon (SOC). The substrate processing apparatus **1** includes: a carrier block **2** and a processing block **3** adjacent to each other; and a controller **100** (control unit).

The carrier block **2** performs a carry-in of the wafer W into the substrate processing apparatus **1** and a carry-out of the wafer W from the substrate processing apparatus **1**. For example, the carrier block **2** is capable of supporting a plurality of carriers **11** for wafers W, and is equipped with a transfer arm A**1** as shown in FIG. **2**. Each carrier **11** accommodates therein a multiple number of, for example, circular wafers W. The transfer arm A**1** takes out a wafer W from the carrier **11**, delivers the taken wafer W into the processing block **3**, receives the wafer W from the processing block **3** and returns the received wafer W back into the carrier **11**.

The processing block **3** includes a plurality of liquid processing units U**1**, a plurality of ashing units U**2** (ashing apparatuses) and a transfer arm A**2** configured to transfer the wafer W into these units. Each liquid processing unit U**1** is configured to perform a processing (coating processing) of forming an organic film by supplying a processing liquid for hard mask formation onto a surface of the wafer W. Each ashing unit U**2** is configured to perform a heat treatment for turning the coating film into a hard mask and a processing (ashing processing) of removing a protective film partially by ashing. Within the processing block **3**, a shelf unit U**10** is provided at the side of the carrier block **2**. The shelf unit U**10** is composed of a multiple number of cells arranged in the vertical direction.

The controller **100** controls the carrier block **2** and the processing block **3** to perform the coating processing, the heat treatment and the ashing processing upon the wafer W. For example, the controller **100** first controls the transfer arm A**1** to transfer the wafer W within the carrier **11** into the shelf unit U**10**. Then, the controller **100** controls the transfer arm A**2** to transfer the wafer W of the shelf unit U**10** into the liquid processing unit U**1**, and controls the liquid processing unit U**1** to perform the coating processing on the wafer W. Thereafter, the controller **100** controls the transfer arm A**2** to transfer the wafer W from the liquid processing unit U**1** into the ashing unit U**2**, and controls the ashing unit U**2** to perform the heat treatment and the ashing processing on the wafer W. Subsequently, the controller **100** controls the transfer arm A**2** to transfer the wafer W from the ashing unit U**2** into the shelf unit U**10**, and controls the transfer arm A**1** to return the wafer W from the shelf unit U**10** back into the carrier **11**. Through these operations, the coating processing, the heat treatment and the ashing processing upon the single wafer W are completed.

[Configuration of Ashing Unit]

Now, a configuration of the ashing unit U**2** will be explained with reference to FIG. **3** to FIG. **7**. As shown in FIG. **3**, the ashing unit U**2** includes a housing **20**, a rotating/holding unit **30** (posture changing unit), a light irradiating unit **40**, a supporting unit **50**, a distance changing unit **60** and an oxygen supplying unit **70**.

The housing **20** accommodates therein some constituent components of the ashing unit U**2**. By way of example, the housing **20** accommodates therein the rotating/holding unit **30**, the supporting unit **50** and the distance changing unit **60**.

The rotating/holding unit **30** is equipped with a holding unit **31** and a rotation driving unit **32**. The holding unit **31**

is configured to hold, from below, the wafer W horizontally with a front surface Wa of the wafer W facing upwards. The holding unit **31** includes a heat plate **33**. The heat plate **33** is configured to face a rear surface Wb of the wafer W. The heat plate **33** includes, as shown in FIG. **4**, a plurality of heating regions arranged in the diametrical direction of the wafer W. For example, the heat plate **33** includes two heating regions **33***a* and **33***b* concentrically arranged outwards from a center of the wafer W. The heating regions **33***a* and **33***b* incorporate therein heaters individually. As the controller **100** controls the heaters, temperature distributions of the heating regions **33***a* and **33***b* are adjusted individually.

The rotation driving unit **32** rotates both heat plate **33** and the wafer W held by the holding unit **31**. The rotation driving unit **32** rotates the holding unit **31** around a vertical axis passing through centers of the wafer W and the heat plate **33** by using, for example, an electric motor as a power source.

The light irradiating unit **40** is disposed above the housing **20**. The light irradiating unit **40** includes, as shown in FIG. **3** and FIG. **5**, a housing **41**, a light source **42** and a window **43**. The housing **41** accommodates therein at least one light source **42**.

The light source **42** is configured to irradiate processing light for aching the organic film to the front surface Wa of the wafer W held by the holding unit **31**. The processing light is an ultraviolet ray having a wavelength ranging from, e.g., about 10 nm to 300 nm. The light source **42** has, for example, a straight tube shape and may be extended within the housing **41** to be parallel with the front surface Wa of the wafer W. As depicted in FIG. **5**, a plurality of (four in FIG. **5**) straight tube-shaped light sources **42** may be arranged within the housing **41** in one direction with a preset distance therebetween. In such a configuration, as depicted in FIG. **6**, the processing light from the light sources **42** may not be irradiated to the front surface Wa of the wafer W in a uniform manner. That is, a region of the front surface Wa located directly under the light sources **42** may be easily ached. The reason for moving (rotating in the present exemplary embodiment) the wafer W with respect to the light sources **42** is to uniform deviation in the aching which may occur depending on the arrangement of the light sources **42**.

The window **43** is provided at a bottom wall of the housing **41**, facing the holding unit **31**. The window **43** transmits the processing light from the light source **42** into the housing **20**.

The supporting unit **50** is provided under the holding unit **31** within the housing **20**. The supporting unit **50** includes a multiple number of supporting pins **51** protruding upwards. Leading ends of the supporting pins **51** are capable of being inserted through through holes (not shown) of the holding unit **31** and through holes **33***c* of the heat plate **33**. With this configuration, the leading ends of the supporting pins **51** are protruded above or retracted below the heat plate **33** and support the wafer W when the wafer W is carried into or out of the housing **20**.

The distance changing unit **60** is configured to vary a distance between the wafer W held by the holding unit **30** and the light irradiating unit **40**. The distance changing unit **60** moves the rotating/holding unit **30** up and down by using, for example, an electric motor or an air cylinder as a power source. If the distance changing unit **60** moves the rotating/holding unit **30** upwards, a gap between the wafer W and the light irradiating unit **40** is reduced, whereas if the distance changing unit **60** moves the rotating/holding unit **30** downwards, the gap between the wafer W and the light irradiating unit **40** is increased. Further, the distance changing unit **60** also serves as a mechanism configured to allow the leading ends of the supporting pins **51** of the supporting unit **50** to be protruded above or retracted below the heat plate **33**. To be specific, if the distance changing unit **60** lowers the rotating/holding unit **30**, the supporting pins **51** penetrate the holding unit **31** and the heat plate **33**, and the leading ends of the supporting pins **51** are protruded above the heat plate **33**.

The oxygen supplying unit **70** is configured to supply oxygen-containing gas into the housing **20**. The oxygen supplying unit **70** is equipped with a nozzle **71**, a gas source **72** configured to supply oxygen into the nozzle **71** and a valve **73** configured to open or close a path from the gas source **72** into the nozzle **71**. An opening (supply hole) of the nozzle **71** may be opened toward a center of a space between the wafer W and the light irradiating unit **40**. Further, it is desirable that the gas source **72** supplies a gas having an oxygen concentration higher than at least an oxygen concentration of the aforementioned oxygen-containing gas into the nozzle **71** as a gas for adding the oxygen.

The controller **100** includes, as functional components (hereinafter, referred to as "functional modules") for controlling the ashing unit U2, a heat plate control unit **101**, an elevation control unit **102**, a light source control unit **103**, a rotation control unit **104**, a valve control unit **105** and a storage unit **106**, as depicted in FIG. **3**.

The heat plate control unit **101** controls the heat plate **33** to adjust a temperature distribution under the conditions that a difference in the progressions of the ashing between the regions arranged in the diametrical direction of the wafer W is reduced. For example, the heat plate control unit **101** controls the heat plate **33** to decrease a temperature of a heating region corresponding to a region where a progression speed of the ashing (ashing rate) is increased when the temperature distribution is uniform and to increase a temperature of a heating region corresponding to a region where the ashing rate is decreased when the temperature distribution is uniform.

The elevation control unit **102** controls the distance changing unit **60** to move the holding unit **31** and the heat plate **33** up and down. For the purpose, when the wafer W is placed on the heat plate **33**, the elevation control unit **102** controls the distance changing unit **60** to vary the gap between the wafer W and the light irradiating unit **40**.

The light source control unit **103** controls the light source **42** to irradiate the light for ashing to the front surface Wa of the wafer W.

The rotation control unit **104** controls the rotation driving unit **32** to rotate the wafer W. The rotation control unit **104** may control the rotating/holding unit **30** to decrease a rotational speed of the wafer W with a lapse of time from the beginning of the irradiation of the light for ashing to the wafer W.

The valve control unit **105** controls the valve **73** to supply the oxygen-containing gas into the housing **20**.

The storage unit **106** stores previously set control parameters therein. These control parameters include a control target value for the heat plate **33** (for example, a target temperature value of each heating region) which is previously set for the control of the heat plate control unit **101**, a control target value for the distance changing unit **60** (for example, a target height value of the holding unit **31**) which is previously set for the control of the elevation control unit **102**, a control target value for the light source **42** (for example, a target light amount value of each light source **42**) which is previously set for the control of the light source control unit **103**, a control target value for the rotation

driving unit **32** (for example, a target rotational speed value and a target rotation number of the holding unit **31**) which is previously set for the control of the rotation control unit **104**, and so forth.

The controller **100** is composed of one or more control computers. By way of example, the controller **100** is equipped with a circuit **110** shown in FIG. **7**. The circuit **110** includes one or more processors **111**, a memory **112**, a storage **113** and an input/output port **114**. The storage **113** has a computer-readable recording medium such as, but not limited to, a hard disk. The recording medium stores therein programs that cause the aching unit U**2** to perform a substrate processing sequence to be described later. The recording medium may be a portable medium such as, by way of example, a non-volatile semiconductor memory, a magnetic disk and an optical disk. The memory **112** temporarily stores thereon the programs loaded from the recording medium of the storage **113** and operation results by the processor **111**. The processor **111** constitutes the aforementioned individual functional modules by executing the programs in cooperation with the memory **112**. The input/output port **114** performs an input and an output of a signal among the heat plate **33**, the transfer arm A**2**, the rotation driving unit **32**, the light source **42**, the distance changing unit **60** and the valve **73** in response to an instruction from the processor **111**. Further, the hardware configuration of the controller **100** may not be limited to constituting the individual functional modules by the programs. For example, each functional modules of the controller **100** may be implemented by a dedicated logical circuit or an ASIC (Application Specific Integrated Circuit) which is an integration of logical circuits.

[Substrate Processing Method]

Now, as an example of a substrate processing method, the substrate processing sequence performed by the ashing unit U**2** will be explained with reference to FIG. **8**, FIG. **10**A and FIG. **10**B.

The controller **100** first performs processes **51** and S**2** shown in FIG. **8**. In the process **51**, the heat plate control unit **101** controls the heat plate **33** to start temperature adjustment of each heating region based on the target temperature value for the heat treatment stored in the storage unit **106**. In the process S**2**, the controller **110** performs a control for carrying the wafer W into the housing **20** of the ashing unit U**2** by controlling the arms A**1** and A**2**.

If the wafer W is carried into the housing **20**, the elevation control unit **102** controls the distance changing unit **60** to lower the holding unit **31** to a position (hereinafter, referred to as "carry-in/carry-out position") where the leading ends of the supporting pins **51** are protruded above the heat plate **33**. Thereafter, the controller **100** controls the transfer arm A**2** such that the wafer W is placed on the supporting pins **51** with the front surface Wa facing upwards (see FIG. **10**A). Then, the elevation control unit **102** controls the distance changing unit **60** to move the holding unit **31** upward until the leading ends of the supporting pins **51** are positioned under the heat plate **33** (see FIG. **10**B). Through these operations, the wafer W is placed on the heat plate **33**, and heating over the wafer W by the heat plate **33** is begun.

Subsequently, the controller **100** performs processes S**3**, S**4** and S**5** shown in FIG. **8**. In the process S**3**, the heat plate control unit **101** waits for a lapse of a predetermined time stored in the storage unit **106**. The predetermined time is previously set to allow the organic film to be sufficiently hardened to become the hard mask. The process S**4** includes an ashing processing of irradiating processing light for ashing to the organic film on the front surface Wa of the wafer W. A specific sequence of the ashing processing will be described later. Then, the controller **100** performs the process S**5**. In the process S**5**, the controller **100** checks whether wafers W as processing targets are all processed.

If it is determined by the controller **100** in the process S**5** that the processing on all the wafers W is not completed, the controller **100** performs a process S**6**. In the process ST**6**, the controller **100** performs a control for carrying the wafer W out of the housing **20** and carrying a next wafer W into the housing **20**. After the process S**6**, the controller **100** returns the processing back to the process S**3**. Then, the heat treatment and the ashing processing are repeated until all the wafers W are processed.

In the process S**5**, if it is determined by the controller **100** that the processing on all the wafers W is completed, the controller **100** performs processes S**7** and S**8**. In the process S**7**, the controller **100** performs a control for carrying the wafer W out of the housing **20**. In the process S**8**, the heat plate control unit **101** controls the heat plate **33** to stop the operations of the heaters. Through the above-described operations, the control sequence over the ashing unit U**2** by the controller **100** is completed.

[Aching Processing]

Now, referring to FIG. **9** to FIG. **11**B, an example of a specific sequence of the ashing processing of the process S**4** will be elaborated. The controller **100** first performs processes S**11** to S**14** shown in FIG. **9**.

In the process S**11**, the heat plate control unit **101** controls the heat plate **33** to vary a temperature of each heating region based on a target temperature value for ashing processing stored in the storage unit **106**. The target temperature value for ashing processing is previously set to decrease a temperature of a heating region corresponding to a region where an ashing rate is increased when the temperature distribution is uniform and to increase a temperature of a heating region corresponding to a region where the ashing rate is decreased when the temperature distribution is uniform. Typically, it is difficult for the ashing processing to be performed at a central portion of the wafer W, whereas the ashing processing more easily takes place at a peripheral portion of the wafer W. On this ground, the heat plate control unit **101** may control the heat plate **33** such that a temperature of a heating region **33***a* corresponding to the central portion of the wafer W becomes higher than a temperature of a heating region **33***b* corresponding to the peripheral portion of the wafer W.

In the process S**12**, the light source control unit **103** controls the light sources **42** to be turned on.

In the process S**13**, the rotation control unit **104** controls the rotation driving unit **32** to start the rotation of the holding unit **31** by the rotation driving unit **32**. Accordingly, the rotation of the holding unit **31**, the heat plate **33** and the wafer W is begun. In the process S**13**, the rotation control unit **104** controls the rotation driving unit **32** such that the wafer W is rotated by 120° at a regular rotation number. Further, the rotation number of the wafer W may be set to be about 1 rpm to about 100 rpm.

In the process S**14**, the light source control unit **103** controls the light sources **42** to be turned off.

Then, the controller **100** performs a process S**15**. In the process S**15**, the controller **100** determines whether the rotation of the wafer W by 120° has been repeated three times. That is, the controller **100** determines whether the wafer W has been rotated one round (whether the rotation angle of the wafer W has reached 360°).

In the process S**15**, if it is determined by the controller **100** that the wafer W is not rotated one round, the controller **100** performs the processes S**12** to S**14** again. Thus, as shown in FIG. **11**A, the wafer W is temporarily stopped after being

rotated at a regular rotation number until the rotation angle reaches 120°, then temporarily stopped after being rotated at the regular rotation number until the rotation angle reaches 240°, and then finally stopped after being rotated at the regular rotation number until the rotation angle reaches 360°. That is, the wafer W intermittently repeats the rotation and the stop of the rotation thereof.

Meanwhile, the light source **42** repeats turning-on and turning-off thereof according to the aforementioned intermittent operation of the wafer W, as depicted in FIG. **11**B. To elaborate, when the rotating operation of the wafer W is begun from a state where the rotation angle of the wafer W is 0° (first posture), the turning-on operation of the light source **42** is also begun. Then, when the stopping operation of the wafer W is begun as the wafer W comes into a state where the rotation angle thereof has reached 120° (second posture), the turning-off operation of the light source **42** is begun. Likewise, when the rotating operation of the wafer W is begun from a state where the rotation angle of the wafer W is 120° (third posture), the turning-on operation of the light source **42** is begun. Then, when the stopping operation of the wafer W is begun as the wafer W comes into a state where the rotation angle thereof has reached 240° (fourth posture), the turning-off operation of the light source **42** is begun. Further, still likewise, when the rotating operation of the wafer W is begun from a state where the rotation angle of the wafer W is 240°, the turning-on operation of the light source **42** is begun. Then, when the stopping operation of the wafer is begun as the wafer W comes into a state where the rotation angle thereof reaches 360°, the turning-off operation of the light source **42** is begun. Accordingly, when the turning-on operation of the light source **42** is begun, the rotation angles of the wafer W (the postures of the wafer W) are all different.

In the process S**15**, if it is determined by the controller **100** that the wafer W has been rotated one round, the controller **100** performs a process S**16**. In the process S**16**, the heat plate control unit **101** controls the heat plate **33** to return the temperature of each heating region to the target temperature value for the heat treatment stored in the storage unit **106**. Through these operations, the ashing processing is completed.

[Effects]

Through researches by the present inventors, however, it is found out that the operation of the light source **42** is not stable at the beginning. That is, immediately after the processing light from the light source **42** is turned on, there may exist some non-uniformity until the processing light comes into a normal state. For this reason, if the wafer W is always at the same rotation angle (posture) when the turning-on of the light irradiating unit is begun, an adverse influence caused by the non-stable beginning of the operation of the light source **42** may be concentrated to a preset place of the wafer W. Specifically, the ashing may not progress sufficiently at this preset place of the wafer W, and there may be caused non-uniformity in the film removal amount of the protective film.

According to the present exemplary embodiment, however, the rotation angles of the wafer W (the postures of the wafer W) are all different whenever the turning-on operation of the light source **42** is begun. Therefore, the adverse influence caused by the non-stable beginning of the operation of the light source **42** is suppressed from being concentrated to the preset place of the wafer W. Therefore, when ashing the protective film formed on the front surface Wa of the wafer W, uniformity in the film removal amount by the ashing within the surface of the wafer W can be improved.

In the present exemplary embodiment, the rotation number of the wafer W may be set to be in a range from 1 rpm to 100 rpm. In this case, the wafer W is rotated at a relatively high rotation number at least in an initial stage of the ashing processing (initial processing). In the initial processing, a removing rate tends to be large, as compared to that in the subsequent processing. Therefore, in the initial processing where the removing rate is relatively large, a larger area of the wafer W is ached. Hence, it is possible to further improve the uniformity in the film removal amount by the ashing within the surface of the wafer W.

(Other Modification Examples)

So far, the exemplary embodiment has been described. However, it should be noted that various changes and modifications may be made within the scope of the present disclosure.

(1) For example, instead of the ashing processing shown in FIG. **9**, an ashing processing shown in FIG. **13** may be performed. In this case, the controller **100** first performs processes S**21** to S**24**. Since the processes S**21**, S**22** and S**24** are the same as the processes S**11**, S**12** and S**14** of FIG. **9**, respectively, redundant description thereof will be omitted.

In the process S**23**, the rotation control unit **104** controls the rotation driving unit **32** to start the rotation of the holding unit **31** by the rotation driving unit **32**. Accordingly, the rotation of the holding unit **31**, the heat plate **33** and the wafer W is begun. In the process S**23**, the rotation control unit **104** controls the rotation driving unit **32** such that the wafer W is rotated one round at a rotation number ω**1** (first speed). Here, the rotation number ω**1** may be set to be about 1 rpm to about 100 rpm.

Then, the controller **100** performs processes S**25** to S**27**. Since the processes S**25** and S**27** are the same as the processes S**22** and S**24**, respectively, redundant description thereof will be omitted here.

In the process S**26**, the rotation control unit **104** controls the rotation driving unit **32** to start the rotation of the holding unit **31** by the rotation driving unit **32**. Accordingly, the rotation of the holding unit **31**, the heat plate **33** and the wafer W is begun. In the process S**26**, the rotation control unit **104** controls the rotation driving unit **32** such that the wafer W is rotated one round at a rotation number ω**2** (second speed). Here, the rotation number ω**2** is set to be lower than the rotation number ω**1** (ω**1**>ω**2**).

Referring to FIG. **14**A, during the processes S**22** to S**27**, the wafer W is temporarily stopped after being rotated one round at the rotation number ω**1**, and then stopped after being rotated one round at the rotation number ω**2**. That is, the wafer W repeats the rotation and the stop of the rotation intermittently. Meanwhile, the light source **42** repeats the turning-on and the turning-off according to the intermittent operation of the wafer W, as shown in FIG. **14**B.

Thereafter, the controller **100** performs a process S**28**. Here, since the process S**28** is the same as the process S**16** of FIG. **9**, redundant description thereof will be omitted.

So far, it is assumed that the film removal amount by the ashing remains substantially same regardless of a lapse of time. According to researches by the present inventors, however, it is found out that the film removal amount by the ashing is largest at the beginning of the ashing processing and gradually decreases with a lapse of the processing time, as shown in FIG. **12**.

A cumulative film removal amount and a film removal amount per unit time shown in FIG. **12** are obtained as follows. First, 20 sheets of wafers W are prepared, and the protective film having a substantially same thickness is formed on the front surface Wa of each of the wafer W. Then,

the ashing processing is performed on these 20 sheets of wafers W while changing the irradiation time (processing time) of the processing light to the wafer W from the light source **42** by 1 sec. For example, the ashing processing is performed on a first sheet of wafer W for 1 sec. The ashing processing is performed on a second sheet of wafer W for 2 sec. The ashing processing is performed on a third sheet of wafer W for 3 sec. To generalize, the ashing processing is performed on the Mth wafer for M sec (M is a natural number ranging from 1 to 20).

The film removal amount is measured for each of the 20 sheets of wafers W subjected to the ashing processing. By plotting these film removal amounts, a polygonal line graph in FIG. **12** showing "cumulative film removal amount" is obtained. Further, for all of the wafers W, by subtracting the film removal amount of the $(M-1)^{th}$ sheet of wafer W from the film removal amount of the Mth sheet of wafer, a processing of calculating a difference between the film removal amount of the Mth sheet of wafer W and the film removal amount of the $(M-1)^{th}$ sheet of wafer W is performed. Here, although 0th sheet of wafer does not actually exist, the film removal amount thereof is assumed as zero (0). By plotting these differences, a bar graph of FIG. **12** showing "film removal amount per unit time" is obtained.

According to the present modification example, the rotation number ω**1** of the wafer W at the initial stage of the ashing processing (initial processing) is set to be higher than the rotation number ω**2** of the wafer W in the later stage of the ashing processing (subsequent processing). Therefore, a larger area of the substrate is ached at the initial processing where the removing rate is large. Accordingly, concentration of the influence caused by the initial processing to the preset position of the wafer W is suppressed. As a result, when ashing the protective film formed on the front surface Wa of the wafer W, it is possible to improve the uniformity in the film removal amount by the ashing within the surface of the wafer.

(2) The rotation of the wafer W and the turning-on/off of the light source **42** may be controlled as shown in FIG. **15**A and FIG. **15**B. To elaborate, as depicted in FIG. **15**A, the wafer W is temporarily stopped after being rotated one round at a regular rotation number. Then, the wafer W is temporarily stopped after being rotated at the regular rotation number until the rotation angle reaches 120°, then temporarily stopped after being rotated at the regular rotation number until the rotation angle reaches 240°, and then finally stopped after being rotated at the regular rotation number until the rotation angle reaches 360°. Meanwhile, the light source **42** repeats the turning-on and the turning-off according to the intermittent operation of the wafer W, as shown in FIG. **15**B.

(3) The rotation of the wafer W and the turning-on/off of the light source **42** may be controlled as shown in FIG. **16**A and FIG. **16**B. To elaborate, as depicted in FIG. **16**A, the wafer W is temporarily stopped after being rotated one round at a rotation number ω**1**. Then, the wafer W is temporarily stopped after being rotated at a rotation number ω**2** until the rotation angle reaches 120°, then temporarily stopped after being rotated at the rotation number ω**2** until the rotation angle reaches 240°, and then finally stopped after being rotated at the rotation number ω**2** until the rotation angle reaches 360° ($\omega 1 > \omega 2$). Meanwhile, the light source **42** repeats the turning-on and the turning-off according to the intermittent operation of the wafer W, as shown in FIG. **16**B.

(4) The rotation of the wafer W and the turning-on/off of the light source **42** may be controlled as shown in FIG. **17**A and FIG. **17**B. To elaborate, as depicted in FIG. **17**A, the wafer W is temporarily stopped after being rotated at a regular rotation number until the rotation angle reaches 270°; temporarily stopped after being rotated at the regular rotation number until the rotation angle reaches 180° (540°); temporarily stopped after being rotated at the regular rotation number until the rotation angle reaches 90° (810°), and then finally stopped after being rotated at the regular rotation number until the rotation angle reaches 360° (1080°). Meanwhile, the light source **42** repeats the turning-on and the turning-off according to the intermittent operation of the wafer W, as shown in FIG. **17**B.

Alternatively, the rotation of the wafer W and the turning-on/off of the light source **42** may be controlled as shown in FIG. **18**A and FIG. **18**B. To elaborate, as depicted in FIG. **18**A, an operation of stopping the wafer W after rotating the wafer W by 120° at a regular rotation number is repeated until the wafer W is rotated one round. Then, an operation of temporarily stopping the wafer W after rotating the wafer W by 130° at the regular rotation number, temporarily stopping the wafer W after rotating the wafer W by 120° at the regular rotation number and temporarily stopping the wafer W after rotating the wafer W by 120° at the regular rotation number is repeated twice. Meanwhile, the light source **42** repeats the turning-on and the turning-off according to the intermittent operation of the wafer W, as shown in FIG. **18**B. Further, though an angular variation amount of the wafer W at the beginning of the turning-on of the light source **42** is by 10° in the example shown in FIG. **18**A and FIG. **18**B, this angular variation amount can be set as required.

In this case, when the turning-on operation of the light source **42** is begun, the rotation angles of the wafer W (the postures of the wafer W) are all different. Therefore, the adverse influence caused by the non-stable beginning of the operation of the light source **42** is suppressed from being concentrated to the preset place of the wafer W. Therefore, when ashing the protective film formed on the front surface Wa of the wafer W, it is possible to improve the uniformity in the film removal amount by the ashing within the surface of the wafer W.

(5) The wafer W may be moved relatively to the light source **42**. That is, the ashing unit U**2** may be configured such that at least one of the wafer W or the light source **42** is moved. For example, as illustrated in FIG. **19**, the wafer W may be slid in one direction with respect to the light source **42**.

(6) Through researches by the present inventors, the present inventors found out the following. While the light source **42** is turned on, the light source **42** generates heat. Accordingly, if a preset time period elapses after the light source **42** is turned off, a temperature of the light source **42** is decreased, so that the temperature of the light source **42** may be different before and after the processing. It is found out that such a temperature variation of the light source **42** results in a variation of the removing rate as well. This is deemed to be because light transmittance of the window **43** is changed as a temperature of the window **43** is varied by the temperature variation of the light source **42**.

In view of this, if a time period during which the light source **42** is turned off is equal to or longer than a predetermined time length, the processing light from the light source **42** may not be irradiated to the wafer W when the light source **42** is turned on, but the processing light from the light source **42** may be irradiated to the wafer W after the temperature of the light source **42** is stabilized (dummy irradiation processing). For example, the light source **42**

may be turned on such that the processing light is not irradiated to the wafer W, and, later on, the processing light may be irradiated to the wafer W. To be more specific, as depicted in FIG. **20**A, a light shielding member **44** may be disposed between the window **43** and the rotating/holding unit **30** (wafer W), and the light source **42** is turned on in this state. As a result, the processing light from the light source **42** is shielded by the light shielding member **44** and hardly reaches the wafer W. Thereafter, as shown in FIG. **20**B, with the light source **42** turned on, the light shielding member **44** is moved not to be located in the space between the window **43** and the rotating/holding unit **30** (wafer W).

With this configuration, the processing light from the light source **42** is irradiated to the wafer W after the temperatures of the light source **42** and the window **43** are stabilized. Therefore, the variation in the removing rate which may be caused by the temperature variation of the light source **42** can be suppressed. Hence, it is possible to further improve the uniformity in the film removal amount by the aching within the surface of the wafer W.

Another method may be adopted to irradiate the processing light from the light source **42** to the wafer W after the temperature of the light source **42** is stabilized. By way of example, the light source **42** may be turned on when the wafer W does not exist within the housing **20**, and the wafer W may be carried into the housing **20** after the temperature of the light source **42** is stabilized. In case that a standby time (interval time) before a next wafer W is carried into the ashing unit U**2** after the wafer W after being subjected to the ashing processing is carried out of the ashing unit U**2** is predetermined (for example, this standby time is previously set in the controller **100**), the light source **42** may be turned on before this standby time elapses. If the temperature of the light source **42** is stabilized by turning the light source **42** on before the standby time passes by, the light source **42** may be turned off before irradiating the processing light from the light source **42** to the wafer W and then turned on again when irradiating the processing light to the wafer W. In this case, it is possible to achieve both the improvement of the uniformity in the film removal amount by the ashing within the surface of the wafer W and the reduction of the power consumption of the light source **42**. The temperature of the light source **42** or the window **43** is measured, and when this temperature is equal to or less than a preset value, the above-described dummy irradiation processing may be performed.

(7) In case that the oxygen-containing gas continuously flows around the wafer W in the ashing processing, the smaller the gap is, the more difficult it is for a flow of the oxygen-containing gas to be formed in the gap, so that the removing rate tends to be decreased. Meanwhile, the larger the gap is, the easier it is for the flow to be formed in the gap, so that the removing rate tends to be increased. Further, in the ashing processing, if the flow of the oxygen-containing gas is not formed around the wafer W, the larger the gap is, the more difficult it is for the processing light from the light source **42** to reach the wafer W, so that the removing rate tends to be decreased. Meanwhile, the smaller the gap is, the easier it is for the processing light from the light source **42** to reach the substrate, so that the removing rate tends to be increased.

Thus, the elevation control unit **102** may control the distance changing unit **60** such that the gap is of a first size at the initial ashing processing and becomes to have a second size different from the first size in the subsequent ashing processing. That is, if the oxygen-containing gas continuously flows around the substrate in the ashing processing, the first size may be set to be smaller than the second size. In this case, it is difficult for the oxygen-containing gas to be supplied to the wafer W at the initial ashing processing. Meanwhile, if the flow of the oxygen-containing gas is not formed around the substrate in the ashing processing, the first size may be set to be larger than the second size. In this case, it is difficult for the processing light from the light source **42** to reach the wafer W at the initial ashing processing. Thus, in any of these two cases, the removing rate may become uniform at the initial ashing processing where the removing rate tends to be larger and in the subsequent ashing processing. Consequently, the uniformity in the film removal amount by the ashing within the surface of the wafer W can be further improved.

(8) In the above-described exemplary embodiment, the wafer W is rotated by 120°. However, the rotation angle of the wafer W per a single time may be set to be 360°/N (N denotes a natural number ranging from 2 to 180 and a divisor of 360).

(9) In the above-described exemplary embodiment, the wafer W is rotated in the same direction. However, the wafer W may be rotated in the backward direction after being rotated in the forward direction.

EXPERIMENTAL EXAMPLES

Experimental examples 1 to 3 and a comparative example are conducted to investigate whether the uniformity in the film removal amount by the ashing within the surface of the wafer is improved when ashing the protective film in the ashing unit U**2** according to the exemplary embodiment.

Experimental Example 1

A disk-shaped wafer W having the protective film formed on the front surface Wa thereof is prepared, and the wafer W is subjected to the ashing processing in the ashing unit U**2**. In the ashing processing, the rotation of the wafer W and the turning-on/off of the light source **42** are controlled as shown in FIG. **21**A and FIG. **21**B. To elaborate, as depicted in FIG. **21**A, a processing of rotating the wafer W by 40° for 10 sec and temporarily stopping the rotation of the wafer W for 3 sec is repeated until the wafer W is rotated one round. Meanwhile, as depicted in FIG. **21**B, the turning-on and the turning-off of the light source **42** are repeated according to this intermittent operation of the wafer W. Accordingly, the processing light from the light source **42** is irradiated to the wafer W for a total time length of 90 sec. Further, in the ashing processing, the heat plate **33** is controlled such that temperatures of all the heating regions **33***a* and **33***b* are substantially same.

Experimental Example 2

A disk-shaped wafer W having the protective film formed on the front surface Wa thereof is prepared, and the wafer W is subjected to the ashing processing in the ashing unit U**2**. In the ashing processing, the rotation of the wafer W and the turning-on/off of the light source **42** are controlled as shown in FIG. **22**A and FIG. **22**B. To elaborate, as depicted in FIG. **22**A, a processing of rotating the wafer W by 120° for 10 sec and temporarily stopping the rotation of the wafer W for 3 sec is repeated until the wafer W is rotated three rounds. Meanwhile, as depicted in FIG. **22**B, the turning-on and the turning-off of the light source **42** are repeated according to this intermittent operation of the wafer W. Accordingly, the processing light from the light source **42** is irradiated to the

wafer W for a total time length of 90 sec. Further, in the ashing processing, the heat plate **33** is controlled such that temperatures of all the heating regions **33***a* and **33***b* are substantially same

Experimental Example 3

A disk-shaped wafer W having the protective film formed on the front surface Wa thereof is prepared, and the wafer W is subjected to the ashing processing in the ashing unit U**2**. In the ashing processing, the rotation of the wafer W and the turning-on/off of the light source **42** are controlled as shown in FIG. **23**A and FIG. **23**B. To elaborate, as depicted in FIG. **23**A, a processing of rotating the wafer W one round for 10 sec and temporarily stopping the rotation of the wafer W for 3 sec is repeated until the wafer W is rotated nine rounds. Meanwhile, as depicted in FIG. **23**B, the turning-on and the turning-off of the light source **42** are repeated according to this intermittent operation of the wafer W. Accordingly, the processing light from the light source **42** is irradiated to the wafer W for a total time length of 90 sec. Further, in the ashing processing, the heat plate **33** is controlled such that temperatures of all the heating regions **33***a* and **33***b* are substantially same

Comparative Example

A disk-shaped wafer W having the protective film formed on the front surface Wa thereof is prepared, and the wafer W is subjected to the ashing processing in the ashing unit U**2**. In the ashing processing, the rotation of the wafer W and the turning-on/off of the light source **42** are controlled as shown in FIG. **24**A and FIG. **24**B. To elaborate, as depicted in FIG. **24**A, the wafer W is rotated one round for 90 sec. Meanwhile, as depicted in FIG. **24**B, the turning-on and the turning-off of the light source **42** are repeated according to this intermittent operation of the wafer W. Accordingly, the processing light from the light source **42** is irradiated to the wafer W for a total time length of 90 sec. Further, in the ashing processing, the heat plate **33** is controlled such that temperatures of all the heating regions **33***a* and **33***b* are substantially same

(Results)

To investigate the uniformity of the film removal amount by the ashing within the surface of the wafer, Range (%) is calculated for each of the experimental examples 1 to 3 and the comparative example. Here, the Range (%) is a value obtained by dividing a difference between a maximum value and a minimum value of the removing rate by the removing rate. The Range (%) of the experimental example 1 is 7.1. The Range (%) of the experimental example 2 is 6.3. The Range (%) of the experimental example 3 is 5.1. The Range (%) of the comparative example is 8.1. The Range (%) in each of the experimental examples 1 to 3 is smaller than that of the comparative example. As can be seen from this, according to the experimental examples 1 to 3, as compared to the comparative example, it is found out that the uniformity in the film removal amount by the aching within the surface of the wafer is improved.

Meanwhile, a distribution of the film removal amount within the surface of the wafer is measured for each of the experimental examples 1 to 3 and the comparative example. The distribution of the film removal amount within the surface of the wafer W in the experimental example 1 is shown in FIG. **25**A. The distribution of the film removal amount within the surface of the wafer in experimental example 2 is shown in FIG. **25**B. The distribution of the film removal amount within the surface of the wafer in the experimental example 3 is shown in FIG. **26**A. The distribution of the film removal amount within the surface of the wafer in the comparative example is shown in FIG. **26**B. In FIG. **25**A to FIG. **26**B, a bright portion indicates a small film removal amount, whereas a dark portion indicates a large film removal amount. Based on FIG. **25**A to FIG. **26**B, the uniformity in the film removal amount at a peripheral portion of each wafer W in a circumference direction is investigated. As a result, the experimental example 3 shows the highest uniformity; the experiment example 2, the second highest uniformity; the experimental example 1, the third highest uniformity; and the comparative example, the lowest uniformity. Thus, it is found out that the uniformity in the film removal amount at the periphery portion of the wafer W in the circumferential direction is improved according to the experimental examples 1 to 3, as compared to the comparative example.

From the foregoing, it will be appreciated that various embodiments of the present disclosure have been described herein for purposes of illustration, and that various modifications may be made without departing from the scope and spirit of the present disclosure. Accordingly, the various embodiments disclosed herein are not intended to be limiting. The scope of the inventive concept is defined by the following claims and their equivalents rather than by the detailed description of the exemplary embodiments. It shall be understood that all modifications and embodiments conceived from the meaning and scope of the claims and their equivalents are included in the scope of the inventive concept.

We claim:

1. An ashing method, comprising:

a first process of irradiating, to a surface of a substrate having an organic film formed on the surface thereof, processing light for ashing the organic film from a light irradiating unit while changing a posture of the substrate with respect to the light irradiating unit from a first posture to a second posture; and

a second process of irradiating, after the first process, the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture.

2. The ashing method of claim **1**,

wherein the substrate is rotated with respect to the light irradiating unit.

3. The ashing method of claim **2**,

wherein a rotation number of the substrate in the first process is set to be in a range from 1 rpm to 100 rpm.

4. The ashing method of claim **1**,

wherein a gap between the substrate and the light irradiating unit in the second process is set to be different from the gap between the substrate and the light irradiating unit in the first process.

5. The ashing method of claim **1**, further comprising:

a third process of turning-on, when a preset time elapses after the processing light from the light irradiating unit is turned off or when a temperature of the light irradiating unit after the processing light from the light irradiating unit is turned off is equal to or less than a preset value, the light irradiating unit such that the processing light is not irradiated to the surface of the substrate, and then, irradiating the processing light to the surface of the substrate.

6. The ashing method of claim 5,

wherein the temperature of the light irradiating unit is a temperature of a member which receives light directly from a light source provided in the light irradiating unit.

7. A computer-readable recording medium having stored thereon computer-executable instructions that, in response to execution, cause an ashing apparatus to perform an ashing method as claimed in claim 1.

8. An ashing method, comprising:

a first process as an initial process of irradiating, to a surface of a substrate having an organic film formed on the surface thereof, processing light for ashing the organic film from a light irradiating unit while moving the substrate with respect to the light irradiating unit at a first speed; and

a second process as a subsequent process of irradiating, after the first process, the processing light to the surface of the substrate from the light irradiating unit while moving the substrate with respect to the light irradiating unit at a second speed lower than the first speed.

9. The ashing method of claim 8,

wherein the second process comprises:

irradiating the processing light to the surface of the substrate from the light irradiating unit while changing a posture of the substrate with respect to the light irradiating unit from a first posture to a second posture at the second speed; and

irradiating the processing light to the surface of the substrate from the light irradiating unit while changing the posture of the substrate with respect to the light irradiating unit from a third posture different from the first posture to a fourth posture at the second speed.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 11,049,739 B2
APPLICATION NO. : 16/260342
DATED : June 29, 2021
INVENTOR(S) : Kikai et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Specification

Column 2, Line 52, “ached” should be -- ashed --.

Column 3, Line 22, “ached” should be -- ashed --.

Column 8, Line 1, “aching” should be -- ashing --.

Column 9, Line 24, “aching” should be -- ashing --.

Column 9, Line 38, “ached” should be -- ashed --.

Column 9, Line 40, “aching” should be -- ashing --.

Column 11, Line 12, “aching” should be -- ashing --.

Column 12, Line 22, “[Aching Processing]” should be -- [Ashing Processing] --.

Column 14, Line 9, “ached” should be -- ashed --.

Column 15, Line 30, “ached” should be -- ashed --.

Column 17, Line 19, “aching” should be -- ashing --.

Column 19, Line 58, “aching” should be -- ashing --.

Signed and Sealed this
Twenty-fifth Day of January, 2022

Drew Hirshfeld
Performing the Functions and Duties of the
Under Secretary of Commerce for Intellectual Property and
Director of the United States Patent and Trademark Office